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STUDY PROGRAM OF NASA/GSFC WELD
QUALITY MONITOR SYSTEM

NAS5-21395

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26. Abstract

The Weld Quality Monitor has provided online control through the application of linear transducers. The electronic systems must be upgraded to increase confidence level required in production.

The Weld Quality Monitor has been used with a recent model solid state power supply to evaluate ability to differentiate between sound and defective weld joints. The Weld Quality Monitor has been evaluated on Dumet and Kovar to interconnect materials Nickel and Alloy 180 in weld joints used in microelectronic module fabrication.

Distinct separation was achieved between low strength welds and sound welds by the Quality Monitor. Evaluation performed indicates a drift level at less than 2 percent on a series of 50 consecutive welds.

Operation under shop conditions identified need for controlled electrode impact. This was achieved with pneumatic actuation.

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PREFACE

Microelectronic weld development has advanced through the improvement and redesign of microwelding power supplies and welding heads. Highly reliable welding procedures have been developed and reliable fabrication procedures established to fabricate electronic modules. Yet inspection techniques have not kept pace with weld development. NASA-Goddard has set about to correct this short coming by funding the development and evaluation of the GSFC Weld Quality Evaluator.

Advanced Manufacturing Technology of Martin Marietta Corporation, Orlando Division, was authorized to evaluate the GSFC Weld Quality Monitor under contract NAS5-21395 for a 5 month period starting in April 1971.

The task leader wishes to thank Mr. Lester G. Hall, who did an excellent task as principal investigator; Mr. Ralph Braswell, who performed the majority of developmental welding and mechanical-electronic adaptation of the GSFC Weld Quality Evaluator to the Hughes solid state power supply; to Nancy C. Heaps, who performed the production welding; and to Mr. David W. Pease, who designed and modified the standard Hughes welding head to function as a pneumatically assisted welding head.

The writer also wishes to thank Mr. James A. Mumford of GSFC for his thoughtful management of this contract and to Mr. George A. Simpson of Presentations for the coordination of artwork, editing, and final printing of this report.

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SUMMARY

The objective of this program was to determine, by scientific methods, the stability of the GSFC weld quality monitor and its ability to discriminate between sound and defective welds and to function under production line conditions. This was achieved by establishing optimum welding conditions which are most conducive to discrimination between defective and sound weld joints, and by evaluating the equipments' ability to do so. To achieve this, three power settings were chosen to produce low strength welds, optimum strength welds, and overheated welds.

To achieve a shopworthy system, two weeks were required to adapt the monitor to a recent solid phase power supply, and to debug the new system.

Application to the specified materials combinations has demonstrated the ability of the Weld Quality Monitor to discriminate between low strength and sound welds. In addition, drift was found to be less than two percent during the welding of 40 consecutive welds.

The clamping action of the mechanical, foot activated electrode drive was not consistent. A supplementary pneumatic system was required to obtain consistent embedment readings.

It is concluded that the Weld Quality Monitor System is working satisfactorily, but will require updating of circuitry and readout components to ready it for production.

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I. INTRODUCTION

Martin Marietta Corporation has been funded by Goddard Space Flight Center to evaluate a Weld Quality Monitor built in accordance with GSFC equipment specifications. The monitor was developed and fabricated by Noetec Corporation of Rockville, Maryland. The Monitor utilizes in-process measurement of deformation during welding to predict weld quality. This deformation, termed embedment, is measured by a linear magnetic transducer (LMT) with associated circuitry to an accuracy of 0.0001 inch. This unit is used in conjunction with a standard capacitor discharge power supply to assure weld quality. Should a bad weld be made, the power supply is locked in ''hold'' position until a line supervisor reactivates the unit for welding.

Trial usage of the Weld Quality Monitor by industry was not satisfactory because insufficient time was taken to set up the equipment and evaluate it. As a result, an RFQ was finally issued seeking a company to provide an engineering evaluation and shop tryout of the GSFC Weld Quality Monitor. This report summarizes the capability of the Weld Quality Monitor to differentiate, and its inherent stability.

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II. STATEMENT OF WORK PERFORMED

The GSFC weld quality monitor was evaluated in a 5 month, two-phase program conducted by the Advanced Manufacturing Technology Department of Martin Marietta Corporation, Orlando Division. Phase I of the program consisted of a 3 month laboratory study, followed by Phase II production evaluation and documentation lasting 2 months. Data analysis and documentation was performed during the last month. Essentially, Phase I involved an analytical study of the equipment's ability to discriminate between sound and defective welds. This established the basis for the Phase II evaluation under production conditions.

A. PHASE I

The GSFC weld quality monitor was evaluated in the laboratory to establish its ability to discriminate and to statistically define these limits. The evaluation was based on data procured during the welding of the following materials:

1 0.020 Dumet (Au) to 0.010 x 0.031 nickel ribbon

2 0.020 Dumet (Au) to 0.020 Alloy 180

3 0.018 Kover (Au) to 0.010 x 0.031 nickel ribbon

4 0.018 Kovar (Au) to 0.020 Alloy 180.

Conventional isostrength were established. In addition, four isopressure lines per material combination were evaluated in depth before three-region separation analysis. This data showed:

1 Strength versus embedment

2 Variation (or standard deviation) versus embedment

3 Strength versus energy at constant force

4 Variation in embedment versus strength.

This and subsequent data developed during three-region separation analysis determined:

1 Optimum weld schedules for each combination of materials;

2 Permissible spread in embedment to produce acceptable joints based on criteria cited herein;

3 Upper and lower embedment control limits based on a probability factor of 99 percent at a confidence level of 95 percent;

4 Capability of weld quality monitor to predict weld strength from embedment reading.

1. Three-Region Separation

To meet NASA/GSFC requirements, an in-process monitoring system must perform the functions normally conducted by a quality inspector. This means that it must be able to differentiate between welds made at optimum watt-second settings and settings that can produce an occasional defective weld. Defective welds may occur at watt-second settings which are either above or below the optimum. Past experience has shown that NASA will not accept spitting because of the potential hazard of subsequently delayed shorting caused by expelled metal particles. The optimum weld region (Figure 1) must be free of potential defects produced at watt-second settings both below and above the optimum.

Figure 1 illustrates the location of the defective weld regions on either side of the optimum weld region. These are called the Low Strength region and Overheated region. The baseline, or abscissa, represents the in-process measurable parameter (embedment) and the ordinate, the frequency of occurrence of observed data. The Optimum Weld Region is within the Sound Weld range and between the two defective regions. The Sound Weld Range is essentially the difference between the statistically calculated Low of the Overheated Region and the high of the Low Strength region.

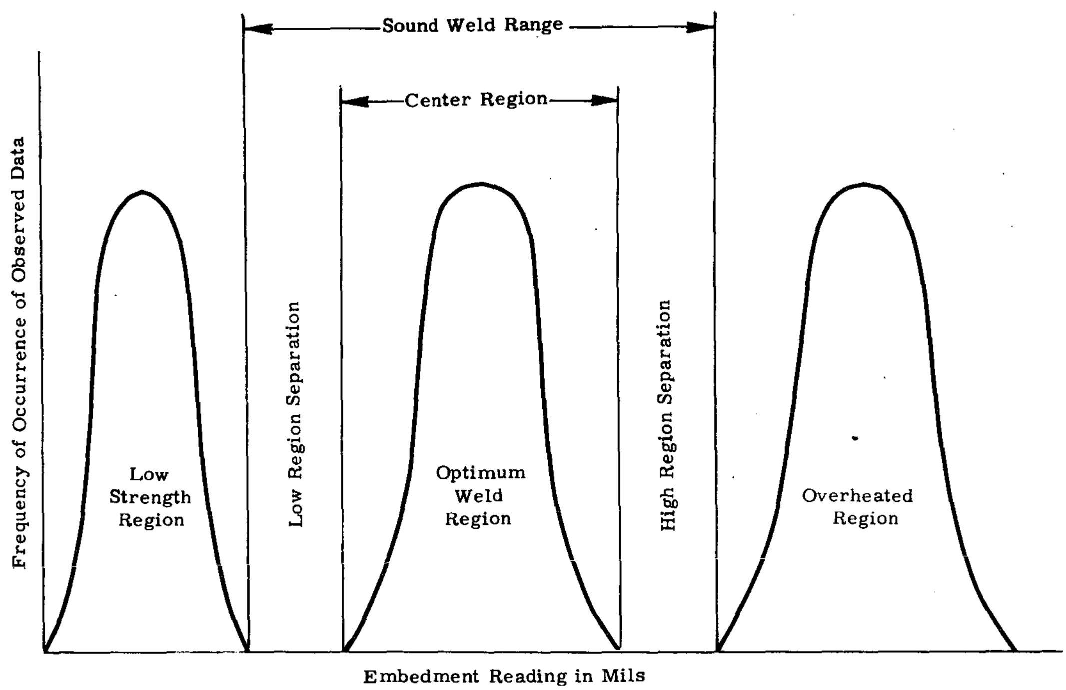


Figure 1. Graphic Illustration of Three-Region Separation

2. Definition of Weld Regions

To better define the three weld regions used in this evaluation, the following definitions were established in compliance with NASA microweld quality inspection requirements. This provides defective regions which were not 100 percent defective on either end of the center weld region but regions which contained occasional defects typical of production experience. The three weld regions are defined as follows:

1 Low Strength Region - This region must contain 25 to 45 good welds in a series of 50. A good weld is one that is 50 percent as strong as the weaker base material of the weld joint or does not exhibit undesirable expulsion, defined later.

2 Optimum Weld Region - The optimum weld region must produce acceptable welds whose strength exceeds 50 percent of the strength of the weaker base material of the weld joint and where none of the following occur:

a Spitting of molten metal during welding;

b Cracking of the weld or heat affected zones;

c Penetration of one material into the other in excess of 50 percent of the thickness of the thinner material;

d Total deformation greater than 35 percent of the thickness of the unwelded joint;

e Expulsion or filleting at the weld not firmly attached to both materials and protruding more than one-half the minimum wire diameter.

3 Overheated Region - The defective high region must contain 25 to 45 good welds in a series of 50 as defined under optimum weld region.

3. Machine Characteristics Evaluation

Analyses were conducted to evaluate inherent sensitivities of both in-process inspection systems to meet NASA quality inspection criteria requiring three-region separation. Data developed during tests performed to achieve three-region separation were evaluated to determine sensitivity, separation, and drift of optimum weld data. These tests are more fully explained as follows:

1 Sensitivity - Sensitivity defines the inherent ability of the in-process inspection system to demonstrate three-region separation. Separation is possible only if the sound weld range is larger than the optimum weld region.

2 Optimum Region Separation - Optimum region separation from defective weld regions reveals the ability of the in-process inspection system to differentiate between the Low, Optimum, and Overheated high regions.

Each region will be determined statistically and will consist of the average value of each region ± three sigma limits. This analysis provides a high degree of confidence in the test results with as few as 50 bits of data from each region.

3 Drift of Optimum Weld Data – Drift is of interest because it demonstrates the ability of the in-process inspection system to repeat under conditions of continued use, as will be encountered in production. The welding system was examined over a period of 30 days and recalibrated as required. Extent of re-calibration was noted as well as overall drift during the 30 day period.

B. PHASE II

Upon completion of the laboratory study, the welding equipment and quality monitor was evaluated on the production floor. All four material lead combinations investigated during Phase I were used for evaluation of production. The GSFC equipment was used on our module fabrication line by one of the production operators.* Daily surveillance was maintained by the principal investigator to establish discriminating capability of the weld quality monitor to record embedment data and the number of defective welds defects.

The GSFC weld quality monitor evaluation program was documented by an interum quarterly report and this final report. The quarterly report was issued after completion of milestone 3. The final report was prepared and mailed to GSFC within 60 days after the completion of the program.

*Operators are certified to NASA requirements.

III. DEVELOPMENT

A. ADAPTATION TO HUGHES POWER SUPPLY

Considerable difficulty was experienced in the initial evaluation of the equipment because of the age of the basic Sippican power supply. Current setting could not be held. Drifting occurred over a 5-second period. After considerable preliminary work had been performed, the Sippican weld head was examined closely because of reoccuring electrode aligning problems; one of the linkage bars was broken. The welding head was repaired by temporarily scavaging one of Martin Marietta's welding heads made by Sippican. Procurement of Sippican replacement parts was difficult because of design change. However, three replacement bars were located and purchased.

While it was possible to conduct a laboratory evaluation of both the GSFC Evaluator and Sippican weld power supply, the Sippican power supply was not found suitable for production usage.

The linear magnetic transducer (LMT) of the Weld Quality Monitor was then mounted onto the Hughes weld head as shown in Figure 2. Figure 3 shows the location of the LMT on both the Sippican and Hughes weld power

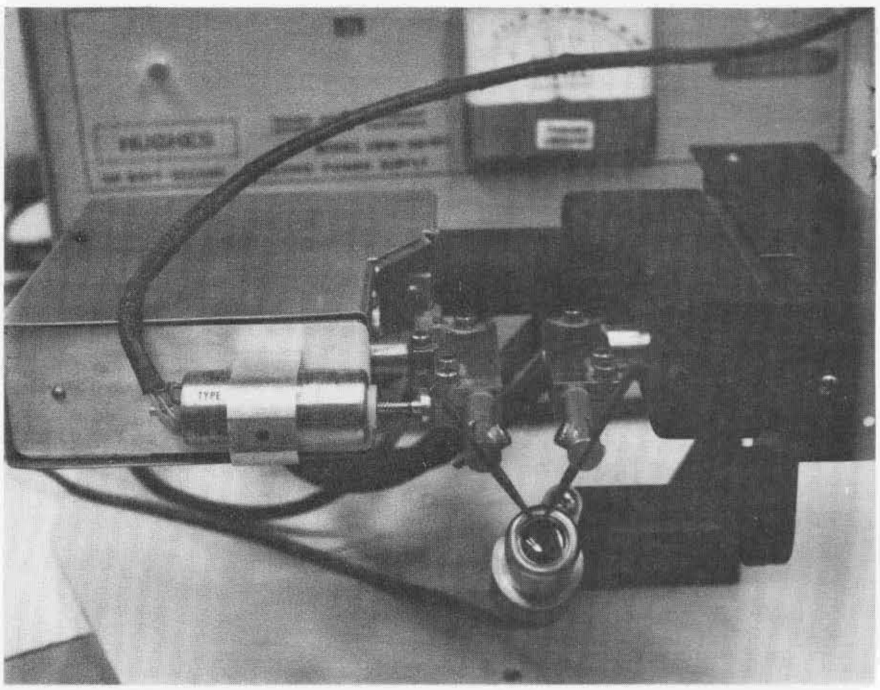
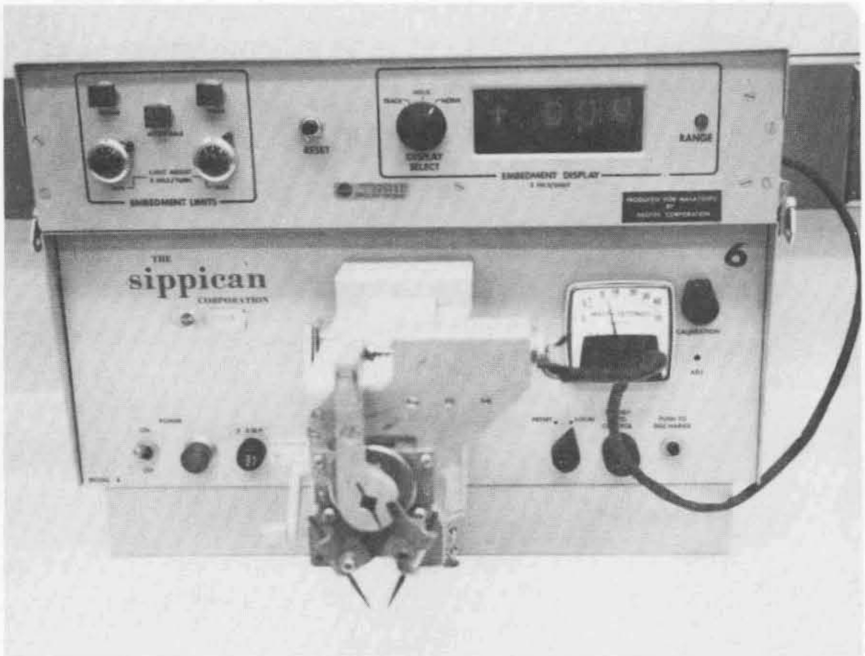


Figure 2. Detail of Mounting Arrangement of GSFC - Weld Quality Monitor LMT Embedment Sensor



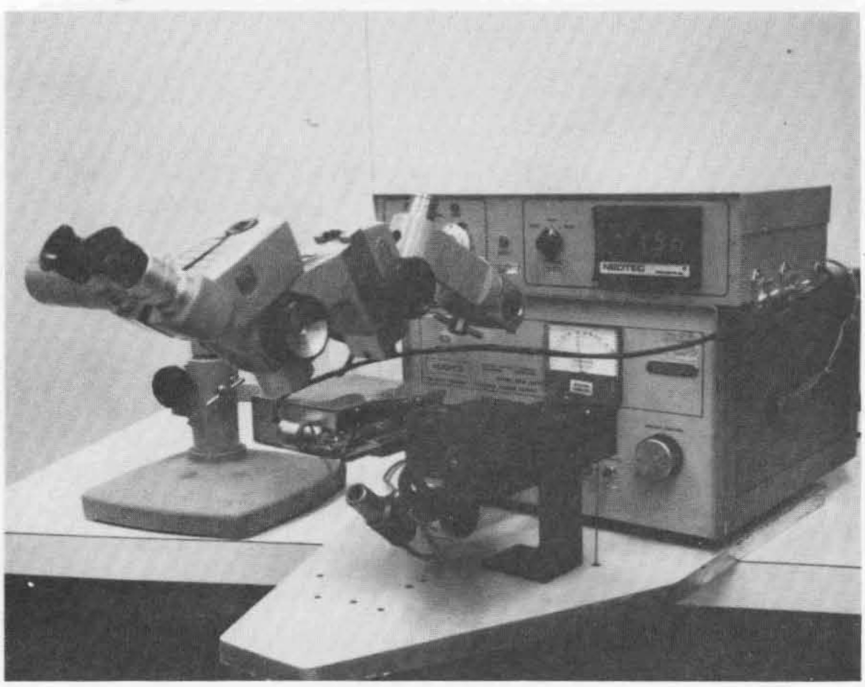


Figure 3. GSFC Weld Quality Monitor Mounted on Both Sippican and Hughes Weld Power Supplies

supplies. A first approach produced a 1 mil error in readout so the LMT was remounted. It was placed directly in-line with the ball bearing movement, as shown, with the LMT sensing foot resting on the moving welding arm. This arrangement did not affect the momentum of the welding arm during the welding cycle. In this position, the LMT shaft followed the movement of the arm through the force exerted by its compressed LMT spring. Since the welding arms must be opened beyond the normal welding position to measure electrode pressure, the LMT spring is placed in a highly compressed state. This exerted significant force on the welding arm to effect the measured welding force. On returning the electrode arm to its normal position, the LMT spring relaxed, exerting less pressure, which lowered the preset/measured welding force. To reduce this variable, a lighter LMT spring was used to lower its maximum compression force from 1 pound to 2 or 3 ounces.

The GSFC weld quality monitor was adapted to the Hughes power supply and has functioned satisfactorily. However, the two familiarization periods required modification, and standardization periods have consumed 5 weeks, placing the program 2 weeks behind schedule.

B. MATERIALS EVALUATION

The four materials combinations specified in the study contract were evaluated for the three region separation tests. Complete separation was achieved in all materials combinations except the first one listed in Table I.

TABLE I

Materials Combinations for GSFC Weld Evaluator Study
1. 0.020 Dumet (Au) to 0.010 x 0.031 nickel ribbon
2. 0.020 Dumet (Au) to 0.020 Alloy 180
3. 0.018 Kovar (Au) to 0.010 x 0.031 nickel ribbon
4. 0.018 Kovar (Au) to 0.020 Alloy 180

In the first material combinations study it was found that a decision had to be made as to where separation was to be preferred. Preliminary runs indicated that separation could be achieved at the bottom end when using a 10 Ws welding setting. A lower setting of 9 Ws produces sufficient scatter such that separation could not be achieved at either end of the optimum weld region.

C. LABORATORY TEST RESULTS

Isostrengths were run for each of the four materials combinations at each of 4 pressure settings. Ten bits of data were run at each 1/2 ws interval from a Low Strength weld region to Overheated weld region at a setting of 2, 4, 6, and 8 lb. welding pressure, respectively. Curves at optimum pressure for each material combination were selected and are shown in Figures 4, 5, 6, and 7. As may be observed in these figures a plot of the corresponding embedment is also shown. Only the maximum and minimum data points are plotted permitting envelope curves to be drawn within which all data points fell.

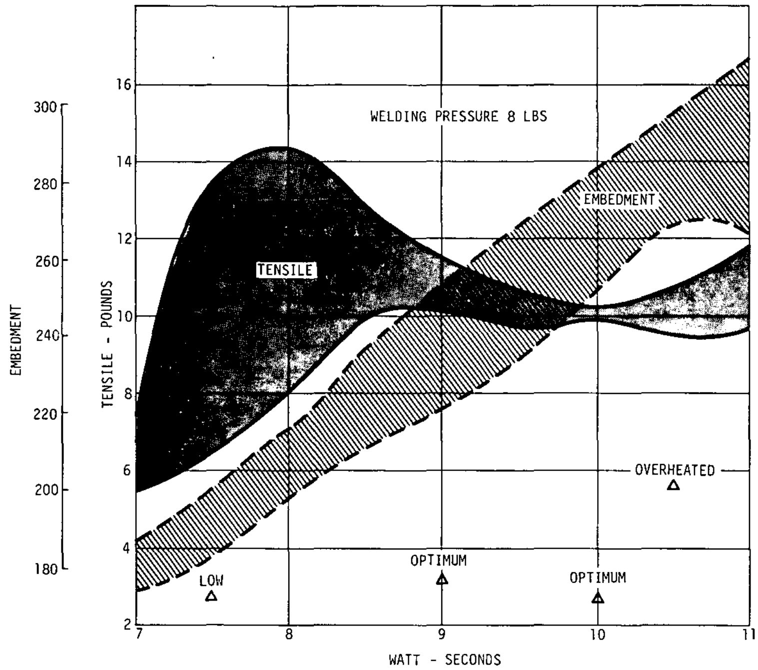


Figure 4. Plot of Tensile and Embedment Versus Welding Energy for 0.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

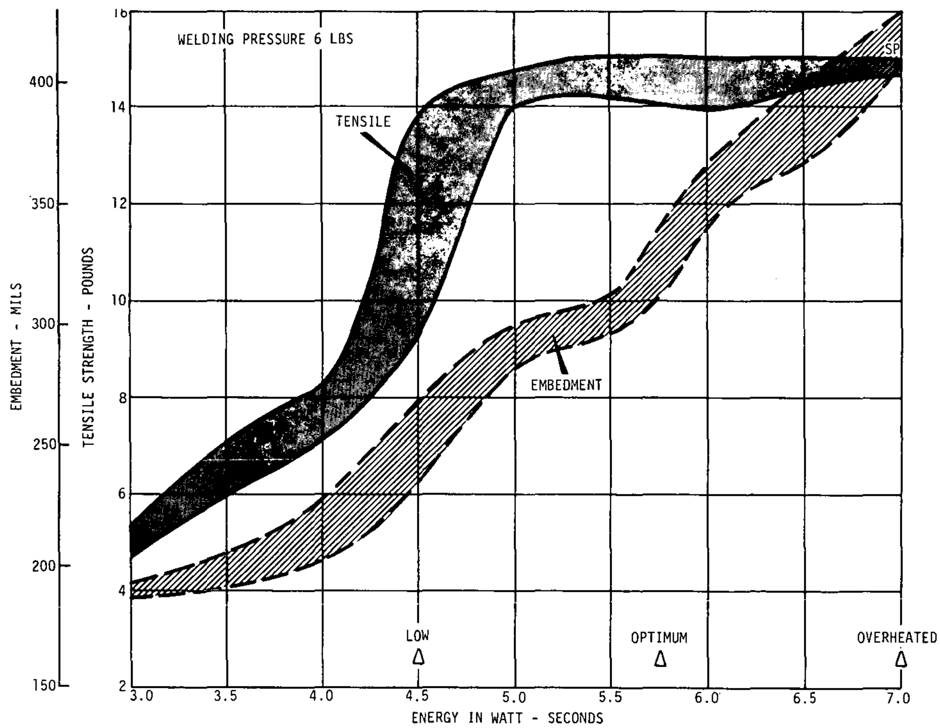


Figure 5. Plot of Tensile and Embedment Versus Weld Energy for 0.020 Dumet (Au) to 0.020 Alloy 180

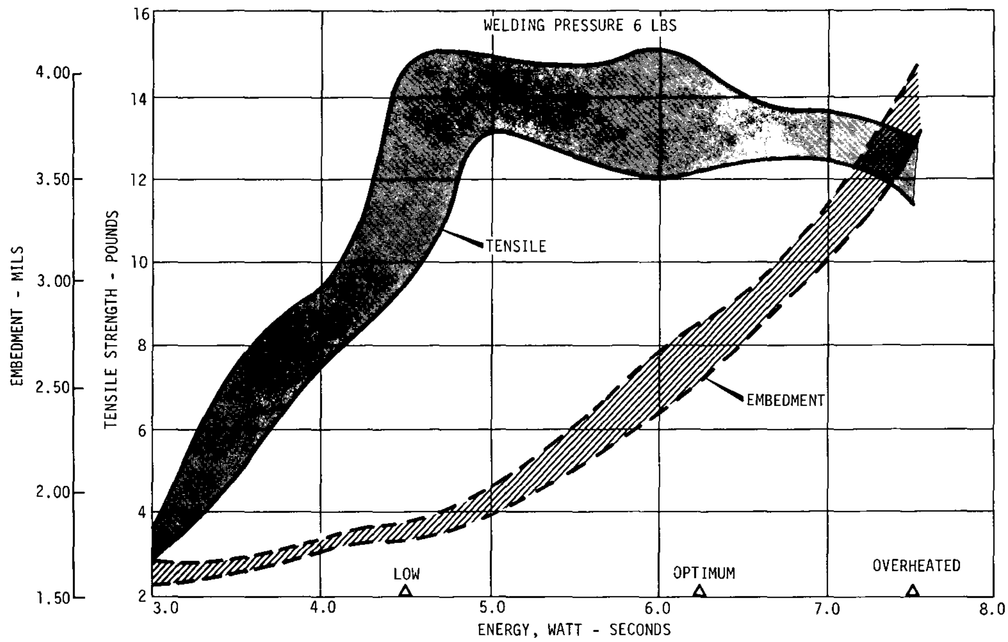


Figure 6. Plot of Tensile and Embedment Versus Welding Energy for 0.017 Kovar (Au) to 0.010 x 0.032 Ni

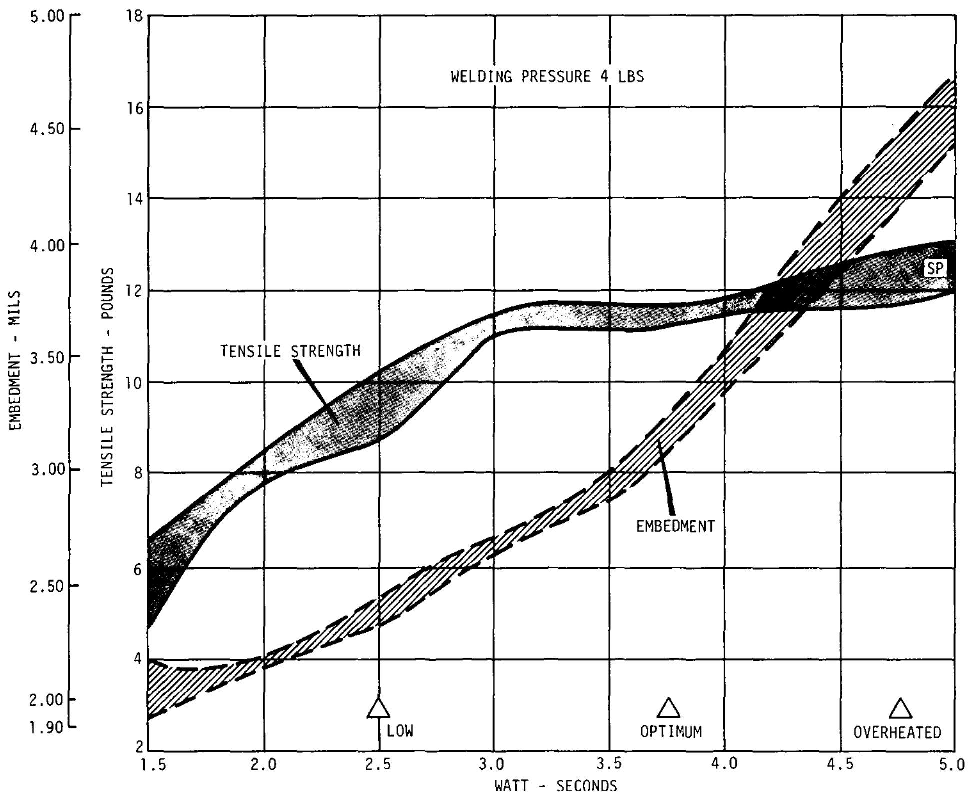


Figure 7. Plot of Tensile and Embedment Versus Weld Energy for 0.017 Kovar (Au) to 0.020 Alloy 180

1. Selection of Optimum Welding Parameters

Optimum welding parameters must be selected to achieve both consistent weld quality and maximum resolution capability of the Weld Quality Monitor. Selection of welding parameters for consistent weld quality are made generally from isostrength diagrams. Selection of welding parameters to achieve maximum Weld Quality Monitor discrimination capability requires additional information of the Tensile-Embedment relationship. Such data was plotted for each of four pressures for all materials combinations and is included in Appendices A through D. The optimum plots are shown in Figures 8 through 11. The data previously plotted in Figures 4 through 7 may be replotted to more clearly show the tensile-embedment relationship with increasing power settings for a selected welding pressure. In these Tensile-Embedment plots, all data points are plotted for each 1/2 Ws increase in weld energy. As may be noted, a distinct correlation exists between tensile strength and embedment in the first quarter of the curve. Increasing welding energy produced a nominal increase in embedment but an abrupt increase in tensile strength. Since tensile values increased from unacceptable to acceptable values, the first quarter of the curve may be called the transition portion of the curve. Here data spread is generally greatest. The second portion of the curve is more stable and may be termed the stable portion of the curve.

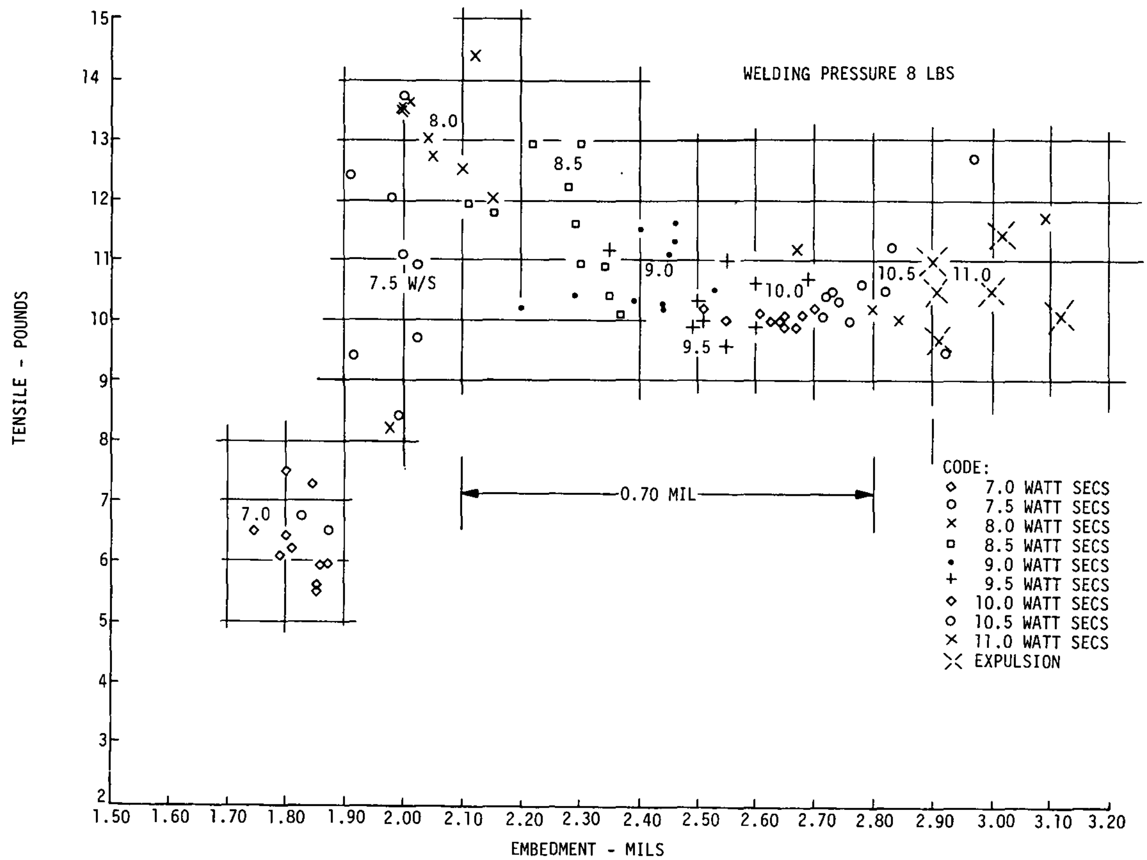


Figure 8. Correlation of Tensile Strength with Embedment for C.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

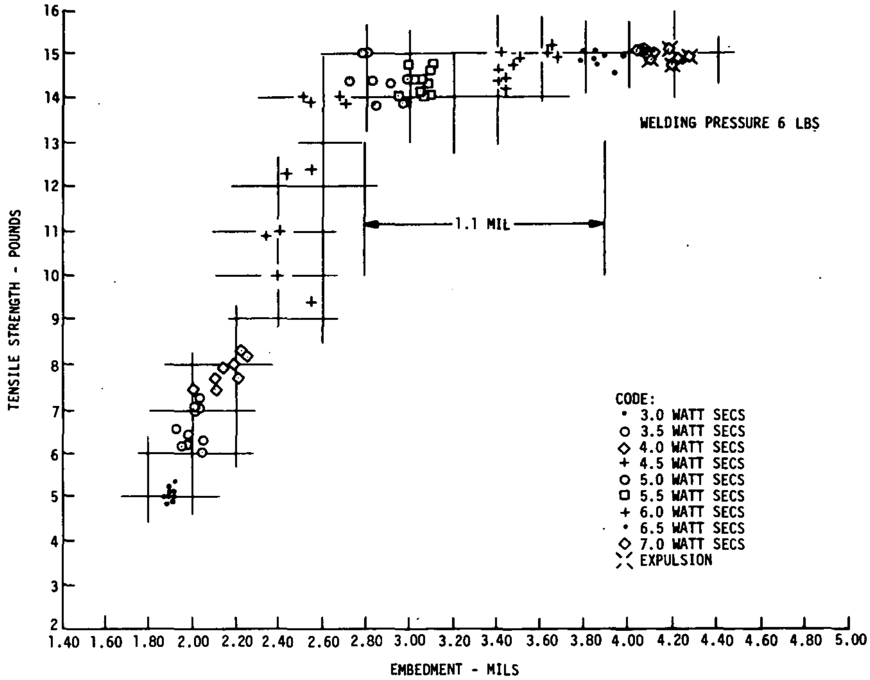


Figure 9. Correlation of Tensile Strength with Embedment for 0.020 Dumet (Au) to 0.020 Alloy 180

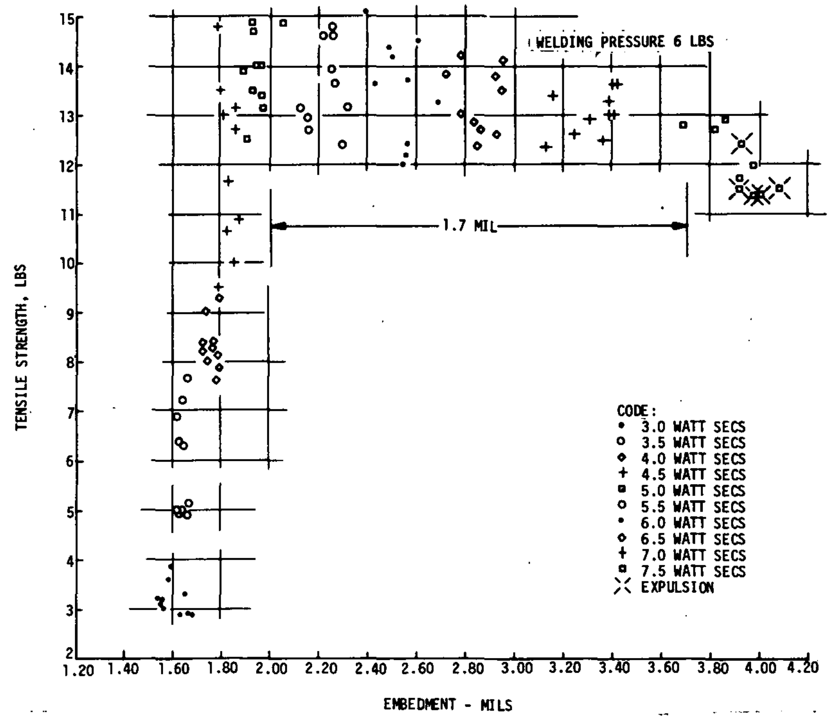


Figure 10. Correlation of Tensile Strength with Embedment for 0.017 Kovar to 0.010 x 0.032 Ni

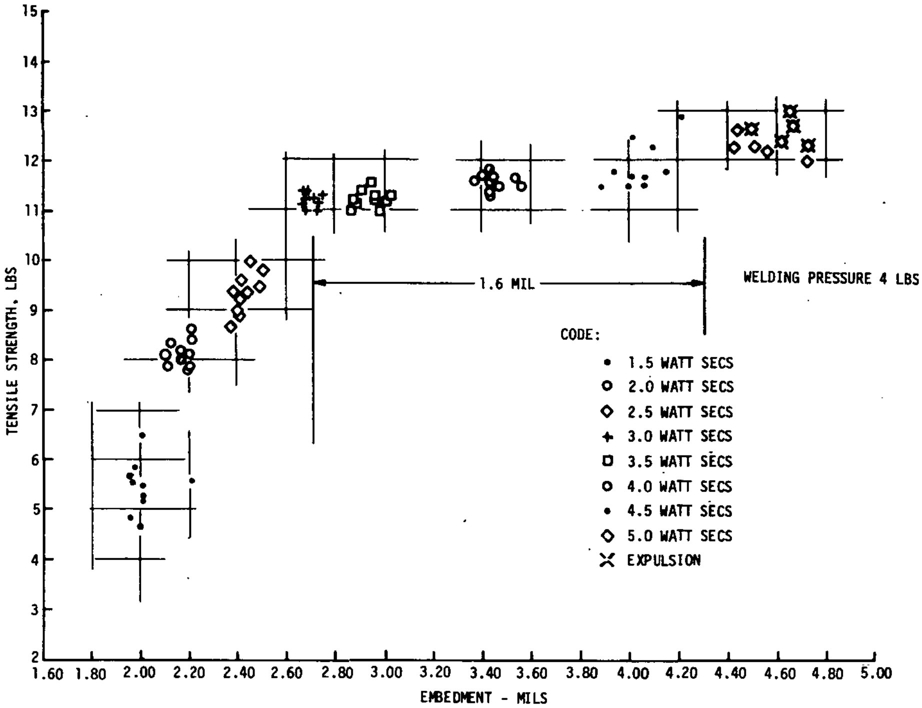


Figure 11. Correlation of Tensile Strength with Embedment for 0.017 Kovar to 0.020 Alloy 180

Certain characteristics may be observed from the stable portion of the curve. Firstly, when component lead materials are welded to nickel ribbon, the tensile values reach a maximum at the upper end of the transition section of the curve (see Figures 8 and 10). From this portion on, tensile strength declines with increasing embedment along the stable portion of the curve. On welding component lead material, Dumet or Kovar, to Alloy 180, this tensile peak does not occur (see Figures 9 and 11). Tensile strength either remains fairly constant or shows a gradual increase in strength during the stable portion of the curve. Secondly, a distinct difference in data grouping is apparent. Tensile variation is considerably less for Alloy 180 interconnect weld joints than for nickel ribbon interconnect joints. Similarily variation of embedment is much less for Alloy 180 interconnect joints whether welded to Dumet or Kovar. This decreased variation in embedment of Alloy 180 weldments is apparent from the tendency of each different Ws weld population to exhibit a minimum of overlapping and/or distinct separation of data populations. In each case these tendencies are more pronounced for a specific component lead material when welded to Alloy 180 than when welded to nickel ribbon. These observations also hold true for the 16 curves included in the appendix, as may be noted from the typical curves in Figures 8 through 11.

Two vertical lines were scribed at a short distance to the right of the Low Strength Weld clusters and to the left of the Overheated Weld clusters.

The extent of the region between these lines are measured as delta embedment mils and used as a criteria for the selection of the optimum weld pressure. This was performed at each of the four isostrength pressures for each of the materials combinations being evaluated. Table II summarizes these measured ranges. As may be seen, the Dumet to Nickel combination shows an optimum region on the 8 lb tensile-embedment plot while the Dumet to Alloy 180 show an optimum range at a welding pressure of 6 lbs. Kovar to nickel and Kovar to Alloy 180 show optimum ranges at 6 and 4 lbs, respectively.

TABLE II

Optimum Weld Pressure Selected by Graphical Analysis

Welding Pressure	Component Lead Materials			
	0.020 Dumet (Au) Lead to:		0.017 Kovar (Au) Lead to:	
	0.01x0.032 Nickel	0.020 Alloy 180	0.010x0.032 Nickel	0.020 Alloy 180
lbs	Δ mils	Δ mils	Δ mils	Δ mils
2	0.30	0.70	0.15	0.65
4	0.40	0.90	0.6	1.6*
6	0.50	1.10*	0.7*	1.4
8	0.70*	0.80	0.3	1.5

*Selected welding pressure

2. Three Region Separation Tests

Each of these optimum tensile strength-embedment correlation plots shown in Figures 8 through 11 were further reviewed for the selection of the Overheated and Low Strength Regions. These regions were to contain a minimum of 25 to 45 good welds in a series of 50 welds. The selected welding currents with the corresponding welding pressures are given in Table III. Upon the establishment of these weld regions a series of 50 bits of data were run for each of the material combinations in the Low Strength, Optimum Weld, and Overheated weld regions. Results of these tests are respectively plotted in Figures 12 through 15. To simplify the plot, only the outer periphery of a data population was plotted. This amounted to approximately 20 points out of the total of 50 run. These were selected by picking the 5 maximum and the 5 minimum tensile values and the 5 maximum and 5 minimum embedment values for each population, respectively. It is very apparent from the first of these plots that the 9 Ws Optimum Weld Region data do not separate from the 7.5 Ws Low Strength Weld Region. Separation can be achieved only by shifting to 10 Ws which then produces interference with the Overheated Weld data. The three remaining plots of the other materials combinations show distinct separation between tests data for the Overheated, Optimum Weld and Low Strength weld regions. The bulk of the test data and statistical analysis is presented in Appendix E.

TABLE III

Welding Parameters Established for the Three Region Separation Test

Ws Settings for Selected Pressures

	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
Region	Ws (Joules)	Pressure (lbs)	Ws (Joules)	Pressure (lbs)	Ws (Joules)	Pressure (lbs)	Ws (Joules)	Pressure (lbs)
Overheated	10.75	8	7.0	6	7.5	6	4.75	4
Optimum Weld	10.0	8	5.75	6	6.25	6	3.75	4
Low Strength	7.75	8	4.5	6	4.5	6	2.45	4

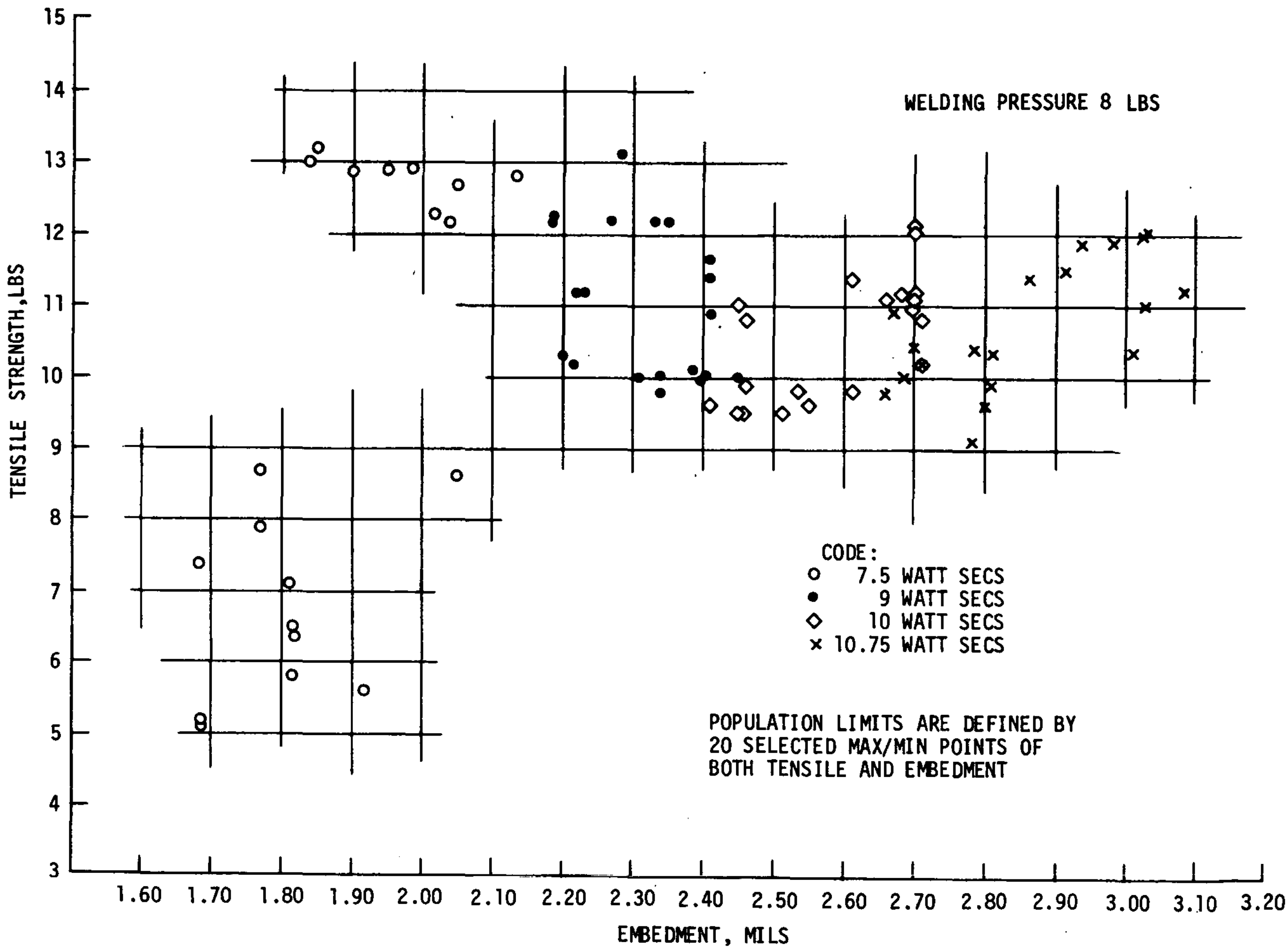


Figure 12. Three-Region Separation Test Data for 0.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

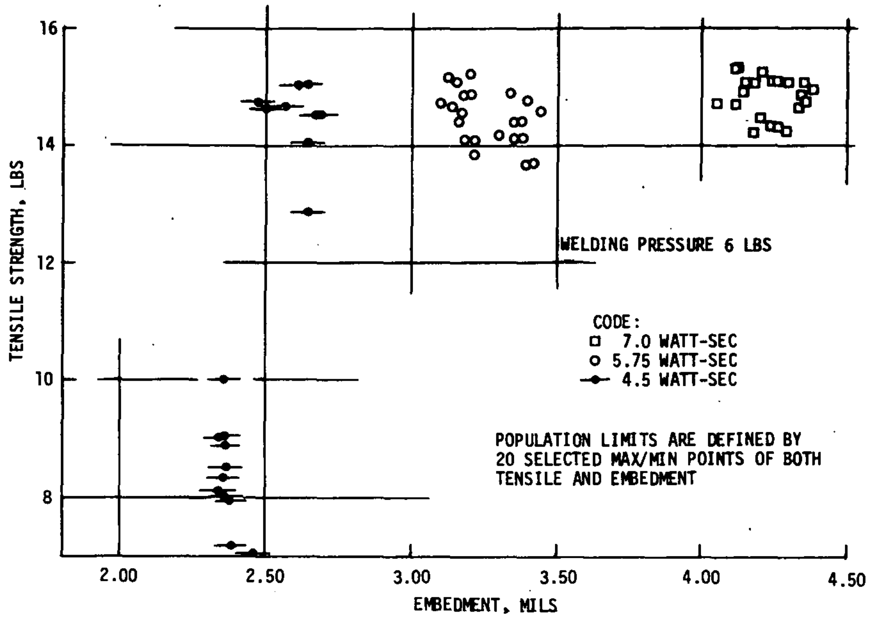


Figure 13. Three-Region Separation Test Data for 0.020 Diameter Dumet (Au) to 0.020 Alloy 180

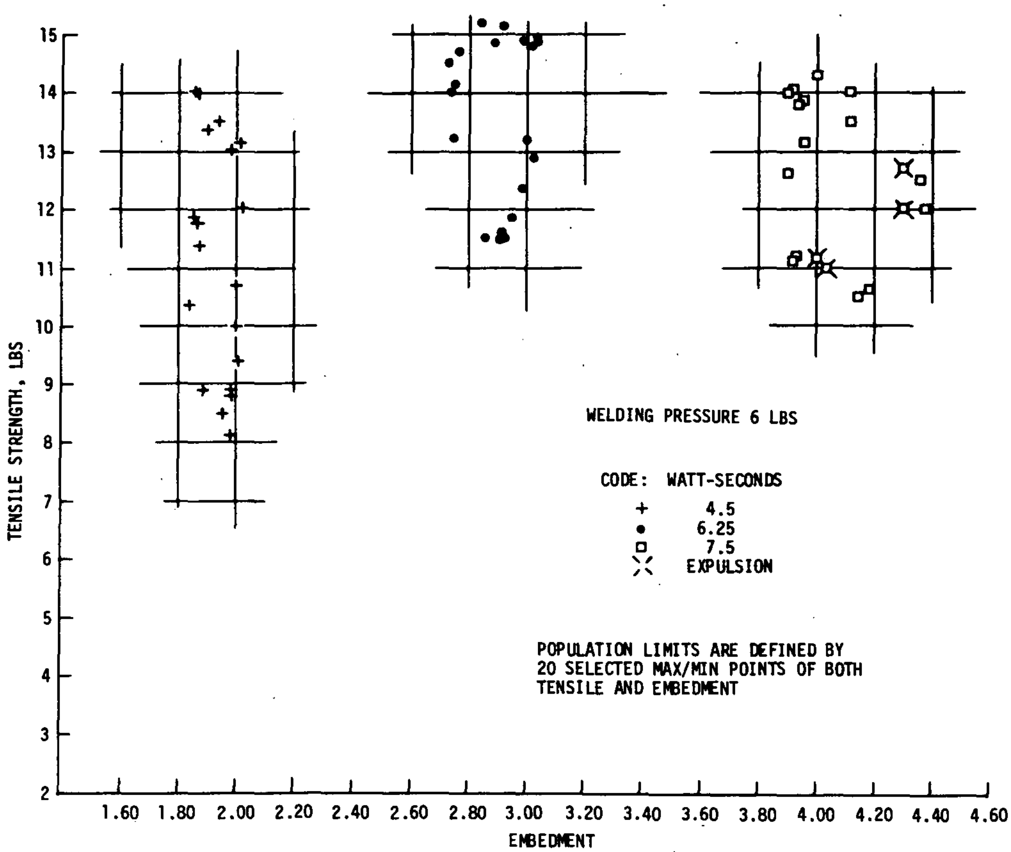


Figure 14. Three-Region Separation Test for 0.017 Kovar (Au) to 0.010 x 0.032 Ni

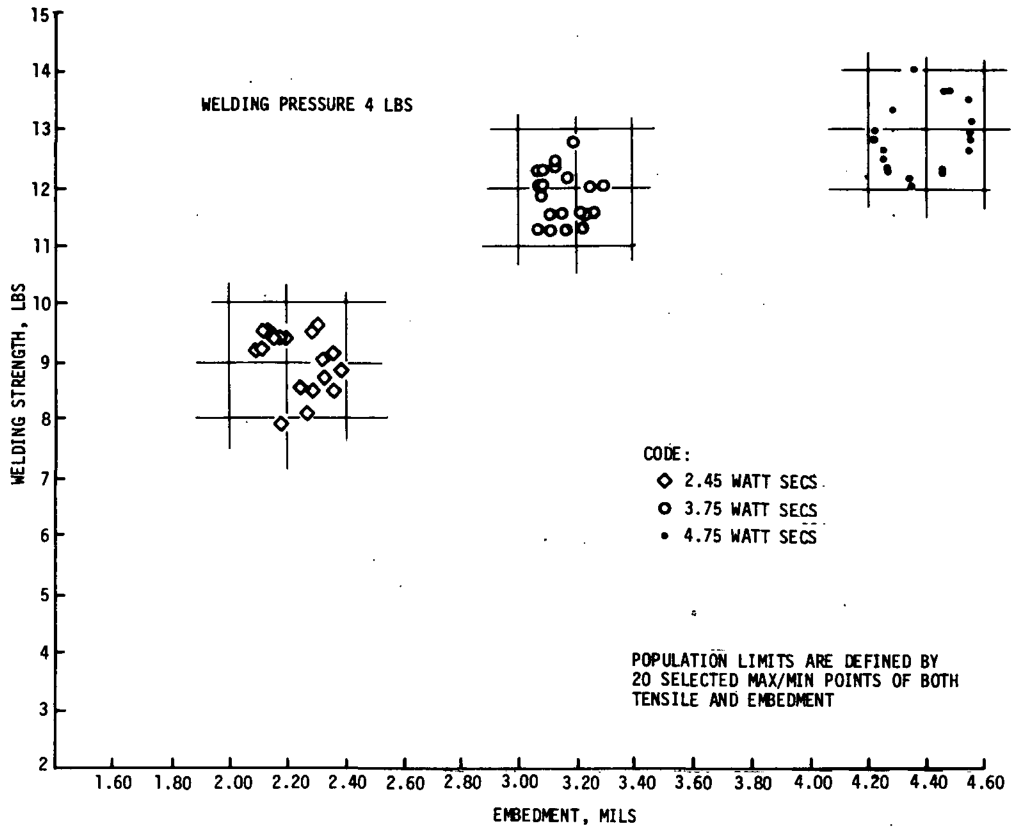


Figure 15. Three-Region Separation Test Data for 0.017 Kovar (Au) to 0.020 Alloy 180

A summary of the statistical analysis is shown in Table IV.

TABLE IV

Summary of Statistical Analysis of Three Region Separation Test
99% Probability with a 95% Confidence Level

Embedment Data

Region	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var
Overheated	2.83	0.04	4.23	0.02	4.11	0.016	4.39	0.019
Optimum Weld	2.57	0.03	3.26	0.025	2.89	0.026	3.14	0.019
Low Strength	1.90	0.05	2.48	0.04	1.93	0.023	2.25	0.026

Strength Data

Region	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
	Average $\bar{X}$ lbs	Coef of Var	Average $\bar{X}$ lbs	Coef of Var	Average $\bar{X}$ lbs	Coef of Var	Average $\bar{X}$ lbs	Coef of Var
Overheated	10.7	0.06	14.8	0.02	12.5	0.07	12.6	0.03
Optimum Weld	10.3	0.06	14.5	0.02	13.4	0.08	11.7	0.05
Low Strength	10.0	0.24	11.8	0.23	10.7	0.13	8.9	0.04

The average values and coefficient of variance are shown for Embedment and Strength Data for each material combination in the three test weld regions: Overheated, Optimum, and Low Strength. As may be observed the average strength of all materials combinations in each region meet minimum strength requirements except Kovar to Alloy 180 in the Low Strength region. A review of the Low Strength data from Table IV shows all of the coefficient of variances to be greater than 0.1, except again by coincidence the aforementioned Kovar to Alloy 180 materials combination. Optimum Weld and high Overheated Weld data show weld strength coefficient of variance of less than 0.1. An analysis of the coefficient of variance of embedment data shows a similar trend except for the Kovar to Nickel ribbon materials combination where the Optimum Weld value is somewhat larger than either the Overheated or the Low Strength Weld region.

The maximum/minimum statistically predicted limits for each of the three weld regions are shown in Table V. This data was calculated to predict limits with a probability of 99 percent and a confidence level of 95 percent. A study of the optimum weld region limits shows distinct separation between the corresponding minimum and maximum of the Overheated defective and Low Strength weld regions, respectively except at one point. Interference or overlap was observed between the Optimum Weld and Overheated Weld regions in the Dumet to Nickel ribbon materials combination. Where a choice must be made it is preferred to have an overlap between the Optimum and Overheated Weld regions instead of the Optimum and Low Strength regions. This insures joint integrity even though some spitting or weld expulsion may be encountered. In those cases where welds do produce spitting the operator should mark that specific weld for rework or close scrutiny by the weld quality inspector. These observations are summarized in Table VI.

TABLE V

Embedment Ranges Established by Statistical Analysis for the Three Region Separation Test

99% Probability with a 95% Confidence Level

	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
Region	Min	Max	Min	Max	Min	Max	Min	Max
Overheated	2.5	3.2	4.0	4.5	3.9	4.3	4.1	4.6
Optimum Weld	2.3	2.8	3.0	3.5	2.65	3.1	3.0	3.3
Low Strength	1.6	2.17	2.15	2.8	1.8	2.1	2.1	2.4

TABLE VI

Conclusions of Three Region Separation Test Designated Separation from Optimum Region

	Dumet (Au) Lead		Kovar (Au) Lead	
Region	Ni Ribbon	Alloy 180	Ni Ribbon	Alloy 180
Overheated	Overlap	Separation	Separation	Separation
Low Strength	Separation	Separation	Separation	Separation

3. Long Time Drift Evaluation

The GSFC weld evaluator has been evaluated over a period of thirty days for draft as shown in Figure 16. Each morning from May 25th to June 23rd, ten welds were made to check equipment calibration. Prior to this test period the welding equipment was turned on and was found to drift throughout the day. The equipment was left in the ‘‘on’’ condition and was allowed to stabilize throughout the weekend. It was calibrated the following Tuesday. From Tuesday morning to Wednesday morning, the equipment deviated +5 3/4 percent. The equipment was recalibrated to an accuracy of -1/2 percent. On recheck Friday, the equipment error increased to -1 3/4 percent. By the following Monday, this error changed to an error of +2 3/4 percent. It was again brought to within 1/4 percent of zero error. Minor drift occurred throughout the next two weeks and did not require recalibration. The next recalibration occurred on June 14th to correct an error of -2 1/2 percent. Through the next 9 days equipment error reached a low of -1 percent ending on June 23rd at -1/4 percent error.

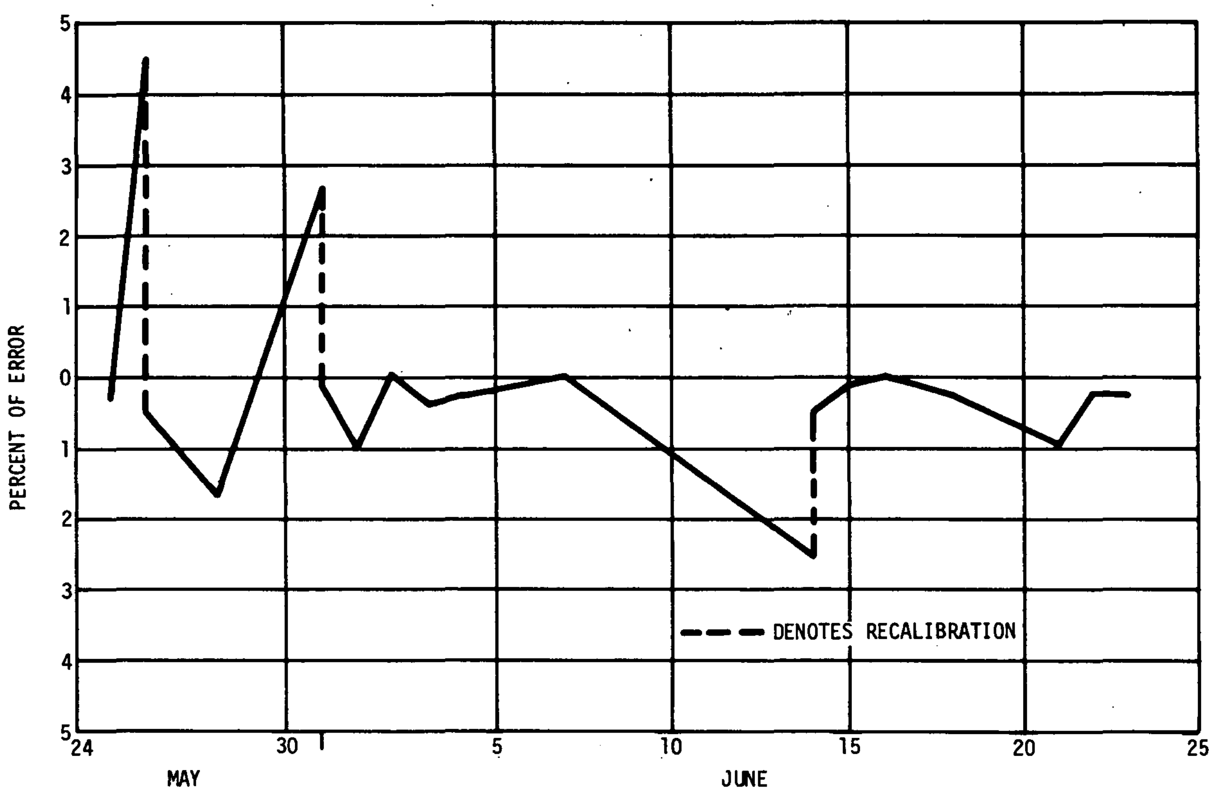


Figure 16. Drift of GSFC Weld Evaluator Over One Month Period

Assuming no corrections were made to the equipment, a cumulative error of +8 percent would have occurred.

The present data indicates that calibration should be performed twice a week with daily check performed each morning. However, after extensive use drift may stabilize by burning in of electrical components.

Redesign of the present circuit for high reliable electrical components should further reduce long time drift.

4. Calibration

Calibration of the equipment was tedious. To achieve a linear read-out both mechanical and electrical adjustments were necessary. A zero reading could be achieved by adjusting the zero potentiometer, but it had some effect on amplification. Likewise an adjustment of the amplification potentiometer had some effect on the zero reading. It was not possible to achieve zero and full scale readings by alternate adjustment of these pots. Only by physically moving the linear magnetic potentiometer could a zero reading by achieved. Scale linearity could then be achieved within 2 to 3 percent although some degree of instability was apparent in the electrical circuit. Slow rotation of the amplification potentiometer slowly changed the display readout until a certain position was reached. At this point the reading would jump 20 to 30 hundredths of a mil with only the slightest movement of the potentiometer. It was found necessary to operate either above or below this position at some built-in error of 2 to 3 percent in numerical readout to achieve a stable setting.

Some rework of the electrical circuit or the addition of an additional linear adjust pot is necessary. Also a mechanical micrometer adjust is necessary to set the zero reading with the present electrical circuit.

Actual calibration was achieved by the use of shim stock. Zero readings were obtained by placing shim stock equivalent to the thickness of the weld joint prior to welding between the welding electrodes, depressing the weld pedal and leaving all shim stock blocks between the electrodes. A calibrated embedment reading was achieved by removing one of the shims after the weld was initiated.

Electrode wear during calibration testing was minimized by the use of three shims and removing only the middle shim to achieve the calibrated embedment reading. The use of a non-conducting center shim eliminated the necessity of setting the weld power supply to zero for each calibration check. This approach makes it possible to check equipment during a production run (or an operator qualification), and eliminates the change of incorrectly resetting the power supply after each calibration check.

D. SHOP EVALUATION

Upon completion of the laboratory evaluation of the GSFC Weld Quality Monitor, the welding equipment and weld quality monitor was moved to the production line. The production operator was permitted three days to become familiar with the equipment during which time many test welds were made. The production operator was used to certify the welding procedure on each of the four materials combinations. All welding pressures were maintained as established in the laboratory phase of the program. Two current settings were changed. In the case of the Dumet to Nickel ribbon materials combination, the welding current for the Optimum Weld region was changed from 10 to 9 1/2 Ws to further centralize the position of the Optimum Welding Region from both defective weld regions. The Optimum Weld current setting for the Kovar to nickel ribbon was changed from 6 1/4 Ws to 5.5 Ws to reduce embedment of the Kovar into the nickel ribbon to less than one-half of the thickness of the nickel ribbon so that all quality requirements would be met. Welding parameters are summarized in Table VII.

TABLE VII

Welding Parameters for Shop Evaluation of GSFC Weld Evaluator

	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
Region	Ws (Joules)	Pressure (lbs)	Ws (Joules)	Pressure (lbs)	Ws (Joules)	Pressure (lbs)	Ws (Joules)	Pressure (lbs)
Operator Certification	9.5	8	5.75	6	5.5	6	3.75	4
Mockup Modules	9.5	8	5.75	6	5.5	6	3.75	4

Having demonstrated that the Optimum Weld Region was clearly separated from both the upper and lower weld regions during Phase I of this study (except in the case of Dumet to nickel), statistical limits were established to a probability of 99 percent and a confidence of 95 percent from the qualification test data. These statistical limits are tabulated in Table VIII and were used to evaluate the ability of the GSFC Weld Quality Monitor to discriminate sound welds in the subsequent Mockup Module test run. Operator Certification and Mockup Module Data is included in Appendix F.

TABLE VIII

Statistical Embedment Limits for Shop Evaluation
Established from Operator Certification

	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
Region	Min mils	Max mils	Min mils	Max mils	Min mils	Max mils	Min mils	Max mils
Optimum Weld	1.02	2.23	2.1	3.4	1.1	2.25	2.54	4.34

In Phase II of this study, mockup modules were employed. These reduced the cost of the program and eliminated the difficulty of procuring a limited quantity of dummy components. It also permitted each weld in each mockup to be destructively tested. Thus, a series of 50 welds were made in several modules and subsequently tensile tested for each materials combination.

Figure 17 shows a standard production module in position for welding. Figure 18 shows a mockup module being welded. The only major difference is that additional nickel was left between welds to permit subsequent tensile testing. As may be observed, the mockup modules were made by inserting lengths of Dumet or Kovar lead material into the styrofoam block and welding nickel ribbon or Alloy 180 wire to the protruding component lead wires of Dumet and Kovar.

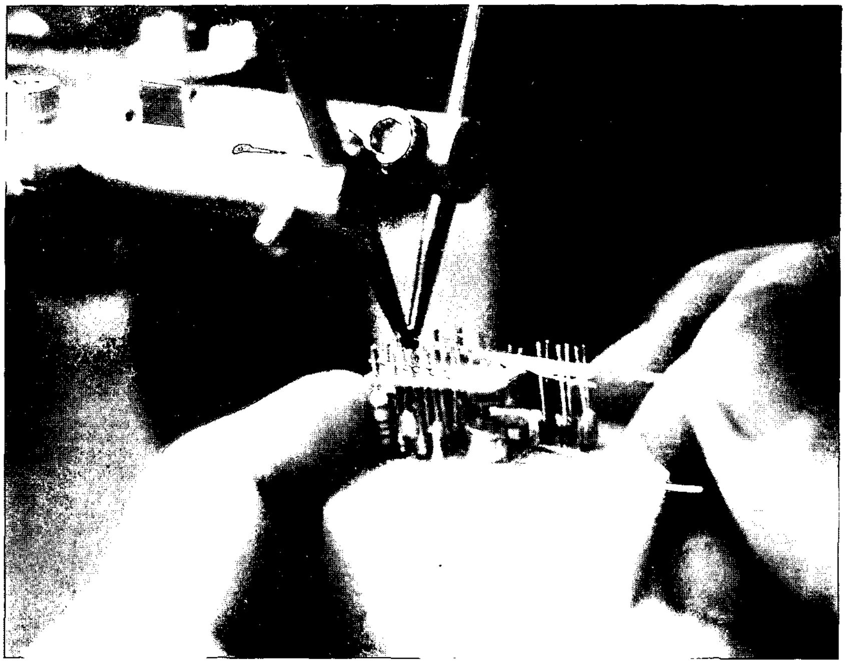


Figure 17. Standard Production Module

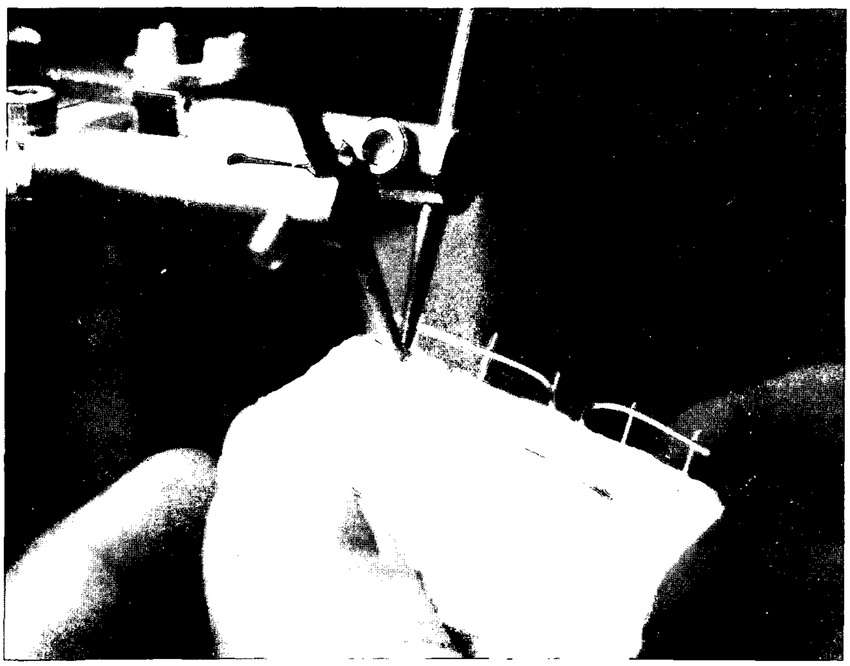


Figure 18. Mockup Module

A typical population of data is shown in Table IX. The results of data analysis is shown in Table X. Average values ($\bar{X}$) as well as coefficients of variance are presented for both strength and embedment. In general, strength values of the Mockup Module runs were equal to or higher than those established during Operator Certification. The coefficients of variance appear reasonable in all instances except in the Dumet to Nickel ribbon Mockup Modules where the value is 0.16. All other values are 0.12 or less.

TABLE IX

Production Mockup
Module Test Data

Material: Positive Side 0.020 Dumet (Au) Neg. Side 0.010 x 0.032 Ni
Electrodes: Top No. 2 Bottom No. 2 Machine HRW 100 Head VTA-60
Heat 9.5 WS **Pressure** 8 lbs

Sample	Embedment	Pull
1	1.68	15.8
2	1.78	16.3
3	1.47	15.7
4	1.59	18.5
5	1.50	17.6
6	1.51	15.8
7	1.85	15.8
8	1.71	14.8
9	1.60	17.3
10	1.57	17.6
11	1.77	14.3
12	1.57	13.4
13	1.78	14.5
14	1.51	10.5
15	1.46	8.5
16	1.47	11.0
17	1.62	9.4
18	1.45	10.6
19	1.91	12.6
20	1.51	15.3
21	1.78	15.6
22	1.84	15.6
23	1.36	13.0
24	1.39	16.8
25	1.41	16.8
26	1.35	14.9
27	1.51	16.9
28	1.50	17.2
29	1.58	17.4
30	1.62	16.4
31	1.56	15.4
32	1.38	14.0
33	1.48	15.0
34	1.24	19.1
35	1.94	17.3
36	1.85	16.9
37	2.08	15.0
38	1.51	17.6
39	1.67	15.7
40	1.38	17.3
41	1.70	16.5
42	1.76	14.6
43	1.77	14.2
44	1.42	16.4
45	1.41	17.2
46	1.27	14.1
47	1.72	17.5
48	1.61	10.5
49	1.31	16.3
50	1.59	18.5

Pull Strength	Embedment
$n = 50$	$n = 50$
$\Sigma X^2 = 12020.35$	$\Sigma X^2 = 127.4570$
$\Sigma X = 765.9$	$\Sigma X = 79.30$
$\frac{\Sigma X^2}{n} = 240.4070$	$\frac{\Sigma X^2}{n} = 2.549140$
$\bar{X} = \frac{\Sigma X^2}{n} = 15.318$	$\bar{X} = \frac{\Sigma X^2}{n} = 1.5860$
$\bar{X}^2 = 234.6411$	$\bar{X}^2 = 2.515396$
$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$	$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$
$= \sqrt{5.7659 = 2.4}$	$= \sqrt{337.44} = 0.1837$
$\sigma_u = 2.42$	$\sigma_u = 0.186$

Actual Embedment Limits 1.24 to 2.08

	Min	Max	$\bar{X}$	σ_u
Statistical Limits Established from Operator Certification	1.02	2.23	1.63	0.19
Actual Module Weld Limits	1.24	2.08	1.59	0.19

Coef. of Var. Pull = 0.16
Coef. of Var. Embedment = 0.12

TABLE X

Statistical Analysis of Mockup Module Data

Embedment Data

Region	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var
Operator Certification	1.63	0.12	2.73	0.08	1.67	0.11	3.4	0.08
Mockup Modules	1.59	0.12	3.06	0.12	1.68	0.10	3.6	0.09

Strength Data

Region	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var	Average $\bar{X}$ mils	Coef of Var
Operator Certification	13.2	0.11	13.0	0.18	14.1	0.09	11.8	0.08
Mockup Modules	15.3	0.16	14.1	0.08	14.4	0.11	12.4	0.06

Table XI summarized the results of the shop evaluation test data. Embedment data from the Mockup Modules fell within the statistical limits as mentioned previously except at the high end of the Optimum Weld Regions for both materials Dumet and Kovar to Alloy 180. Again, fortunately, the higher values obtained indicate that a weld was produced, although expulsion could have occurred. All welds were monitored by the welding operator and an engineer. Actually, no expulsion was observed when these welds were made.

TABLE XI

Mockup Module Max/Min Data Compared to Predicted Statistical Limits

Region	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
	Min mils	Max mils	Min mils	Max mils	Min mils	Max mils	Min mils	Max mils
Operator Certification (Statistical Limits)	1.02	2.23	2.1	3.4	1.1	2.25	2.54	4.34
Mockup Modules (Data Limits)	1.24	2.08	2.3	4.1	1.3	2.17	2.98	4.72

One explanation for this may be accounted for by the fact that the embedment data obtained by the production operator showed a significantly greater spread than that obtained by the laboratory technician. Compare Operator Certification data of Table XI with the Optimum Weld data of Table V. This led to consideration of reducing the ''Operator Factor.''

A consideration of the basic mechanics of embedment led to the conclusion that embedment closely resembled that of hot forging. Two factors being important, temperature and force, it became apparent that the control of one or both of these factors would significantly reduce the random spread in forging and embedment. A few simple tests soon confirmed this hypothesis. Test data produced by the production operator was duplicated by an engineer. The engineer first made 10 welds in the normal manner, another 10 with a quick tromp on the foot pedal, and a last 10 with a slow squeeze action. All embedment data was fairly consistent for each group run, but differed significantly from group to group.

To further checkout the practicality of this concept, a pneumatic cylinder was mechanically attached to the Hughes welding head to perform the function of providing a consistent forge pressure for each weld made.

E. PNEUMATIC WELD HEAD

Upon completion of the shop evaluation studies specified by contract, a feasibility study was run to reduce the spread in test data by reducing the ''operator factor.'' As mentioned this mechanizing Hughes VTA-60 weld head provided pneumatic assist during the welding cycle. The breadboard mechanization is shown in Figure 19 with a closeup in Figure 20. An air cylinder (A) is actuated through a solenoid valve and flow rate regulator when a foot pedal is depressed closing a microswitch. This produced a uniform application of load instead of the variable impact effect produced manually by the conventional foot pedal.

The pneumatic system alone is not satisfactory. The operator needs to manually position the work piece between the electrodes before initiating the weld. A few welds made with only pneumatic pressure system showed this to be true. Once pneumatic pressure was initiated, the electrodes would close rapidly and weld without allowing the operator time to reposition the test joints which is generally required more frequently than not.

The prototype pneumatic weld head used for evaluation of this concept was modified to permit manual closure of the welding electrodes with capability of subsequent application of pneumatic weld pressure to complete the weld cycle. This required two foot pedals which the operator found to be quite comfortable. The operator is shown using the equipment in Figure 21. Her right foot was used in the conventional manner to manually close the welding electrodes while her left foot activated the pneumatic pressure mechanism when the weld joint was finally positioned for welding.

Figure 19. Breadboard of Pneumatic Head

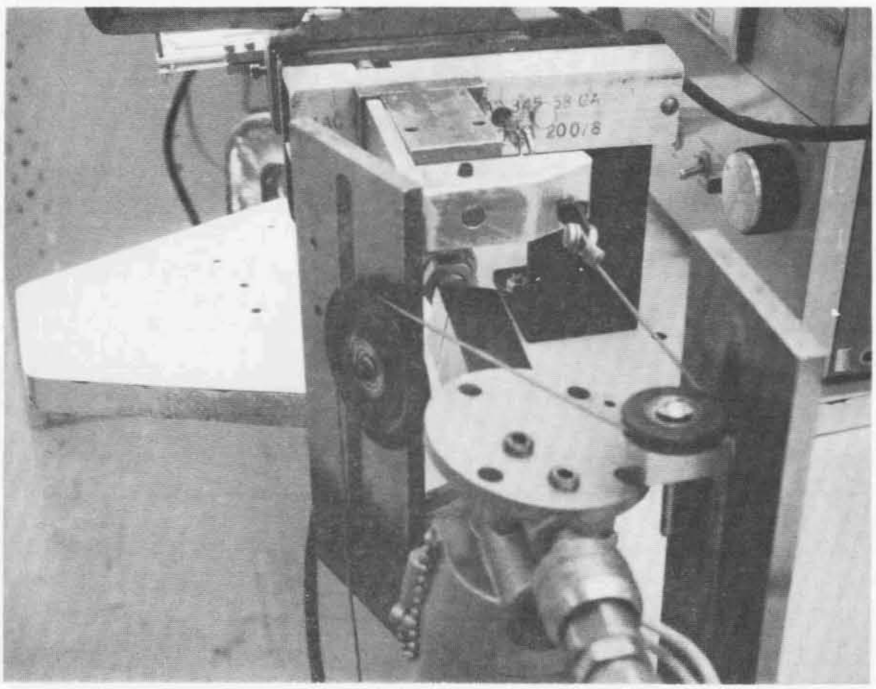


Figure 20. Closeup of Pneumatic Head Mechanization

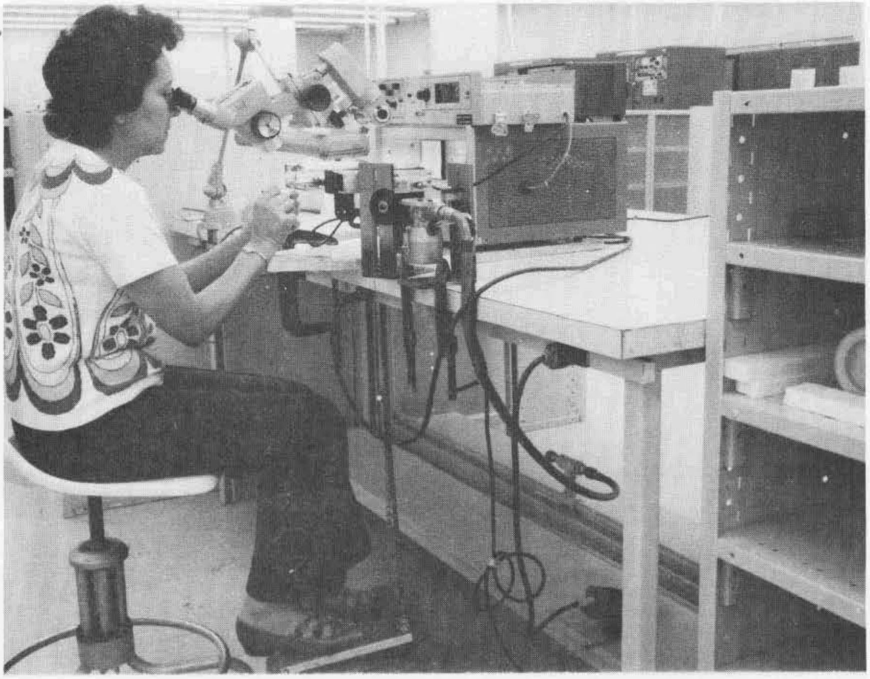


Figure 21. View of Operator Using Pneumatic Head

Standard Versus Pneumatic Head

To obtain a more thorough quantitative evaluation of the forging effect on embedment, comparative tests were run with the standard and the pneumatically assisted welding heads. The production operator performed a series of 50 welds with each of the four welding combinations at the optimum welding condition. The welding conditions used for this evaluation are shown in Table XII. The tabulated data is included in Appendix G.

TABLE XII

Welding Parameters for the Evaluation of the Pneumatic Assisted Welding Head

Region	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
	Watt-sec Joules	Pressure lb	Watt-sec Joules	Pressure lb	Watt-sec Joules	Pressure lb	Watt-sec Joules	Pressure lb
Optimum	10.0	8	5.75	6	4.75	6	3.75	4

Embedment and tensile data are presented in Table XIII. Aside from the fact that embedment and tensile values are on the average higher, the pneumatically assisted weld head significantly reduced the spread in all data.

TABLE XIII

Comparison of Manual versus Pneumatically Assisted
Weld Head at Optimum Weld Region
Calculated to 99 percent Probability with a 95 Percent Confidence Level

	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
Embedment Data	Average $\bar{X}$ (mils)	Coef of Var	Average $\bar{X}$ (mils)	Coef of Var	Average $\bar{X}$ (mils)	Coef of Var	Average $\bar{X}$ (mils)	Coef of Var
Manual Head	2.2	0.14	3.8	0.15	1.2	0.06	2.8	0.04
Pneumatic Head	3.5	0.03	3.8	0.05	1.6	0.04	3.6	0.03
Tensile Data								
Manual Head	12.4	0.14	14.9	0.03	11.1	0.15	11.3	0.04
Pneumatic Head	14.3	0.08	15.0	0.04	15.1	0.04	11.8	0.03

As mentioned earlier, the production operator produced a significant increase in the spread of embedment data. The pneumatically assisted weld head reduced the data spread obtained in the shop to the order of magnitude achieved in the laboratory. Compare Table XIII for pneumatic data developed in the shop to Table IV for standard data developed in the weld lab.

Table XIV summarizes the maximum and minimum limits obtained with both heads as well as the spread in embedment data. Notice that data spread, population range, is reduced in all instances when the pneumatic head is employed. Also note that the maximum reduction in data spread occured with the material where it was most sorely needed. Dumet to Ni ribbon and Dumet to Alloy 180 wire were reduced to one-third of that produced by the standard head. In the Kovar to Ni ribbon combination, little to no change was encountered. In the Kovar to Alloy 180 materials combination the data spread was reduced to about two-thirds of its previous value by the use of the pneumatically assisted weld head.

TABLE XIV

Comparison of Manual versus Pneumatically Assisted Weld Head
at Optimum Weld Region Calculated to
99 Percent Probability with a 95 Percent Confidence Level

Population Limits	Dumet (Au) Lead				Kovar (Au) Lead			
	Ni Ribbon		Alloy 180		Ni Ribbon		Alloy 180	
	Min	Max	Min	Max	Min	Max	Min	Max
Manual Head	1.3	3.2	2.1	5.6	0.94	1.4	2.4	3.2
Pneumatic Head	3.2	3.8	3.2	4.4	2.4	2.9	3.3	3.8
Population Range	Δ mils		Δ mils		Δ mils		Δ mils	
Manual Head	1.9 mils		3.5 mils		0.46 mils		0.8 mils	
Pneumatic Head	0.6 mils		1.2 mils		0.5 mils		0.5 mils	

IV. NEW TECHNOLOGY

The Weld Quality Monitor did not discriminate between sound and overheated welds on welding Dumet to Nickel ribbon. It is proposed that an infrared control system be incorporated to provide control of pulse power while the GSFC Weld Quality Monitor assure freedom from low strength welds. This particular IR system has been built and demonstrated in Martin Marietta's Advanced Manufacturing Technology Laboratories. The IR control was so effective that sound welds were consistently produced whether the weld power supply was set at 20 Ws or 100 Ws.

V. CONCLUSIONS AND RECOMMENDATIONS

The Weld Quality Monitor has demonstrated ability to differentiate between low strength welds and sound welds. The equipment has demonstrated little drift (less than 2 percent) when checked daily and calibrated twice a week. A high level of stability could be achieved when the equipment was allowed to run continuously to stabilize thermally. New electronic design and utilizing state-of-the-art components is recommended to provide a monitor which is suitable for production. Calibration and maintenance could limit effectiveness of present system.

The addition of a pneumatic assist to position the electrodes is also recommended. It provides an inexpensive method of regulating tip pressure and thus assures consistent welds. Quantitative tests run in the production shop comparing the standard weld head with the pneumatically assisted weld head strongly demonstrated the ability of reducing the ''operator factor.'' The four hundred welds made in this comparison consistently confirmed these observations.

The infrared system, developed by Martin Marietta, also provides weld control and should be evaluated for high reliability GSFC systems. Its simplicity, range, and ability to discriminate hot welds is unique. It would be incorporated to achieve feedback control.

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APPENDIX A

CORRELATION OF TENSILE STRENGTH WITH EMBEDMENT

0.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

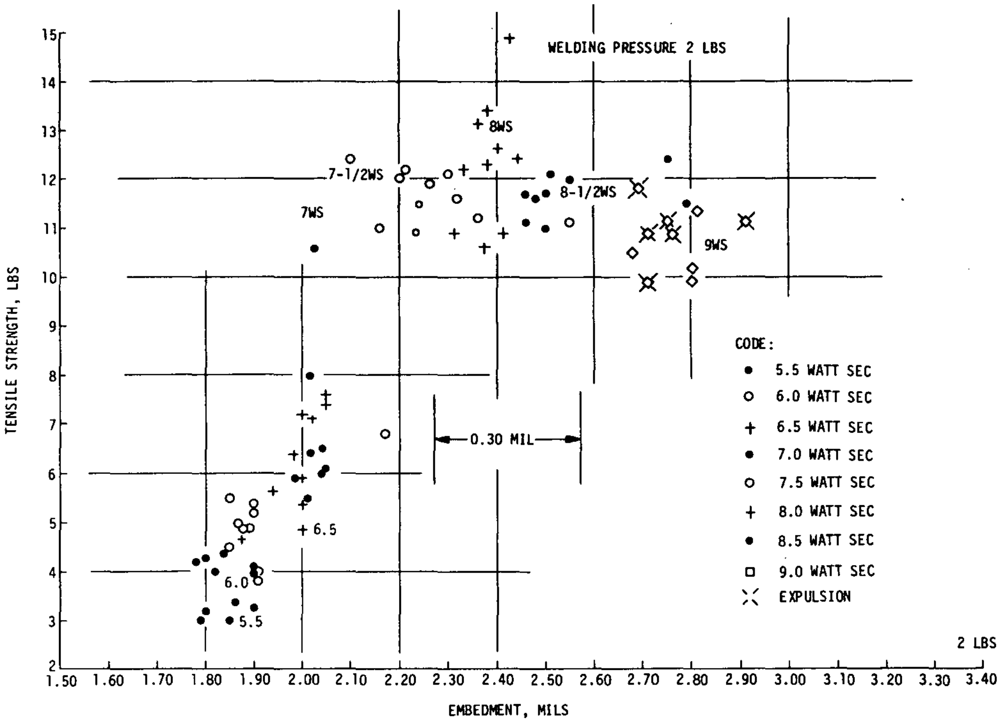


Figure A-1. Correlation of Tensile Strength with Embedment 0.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

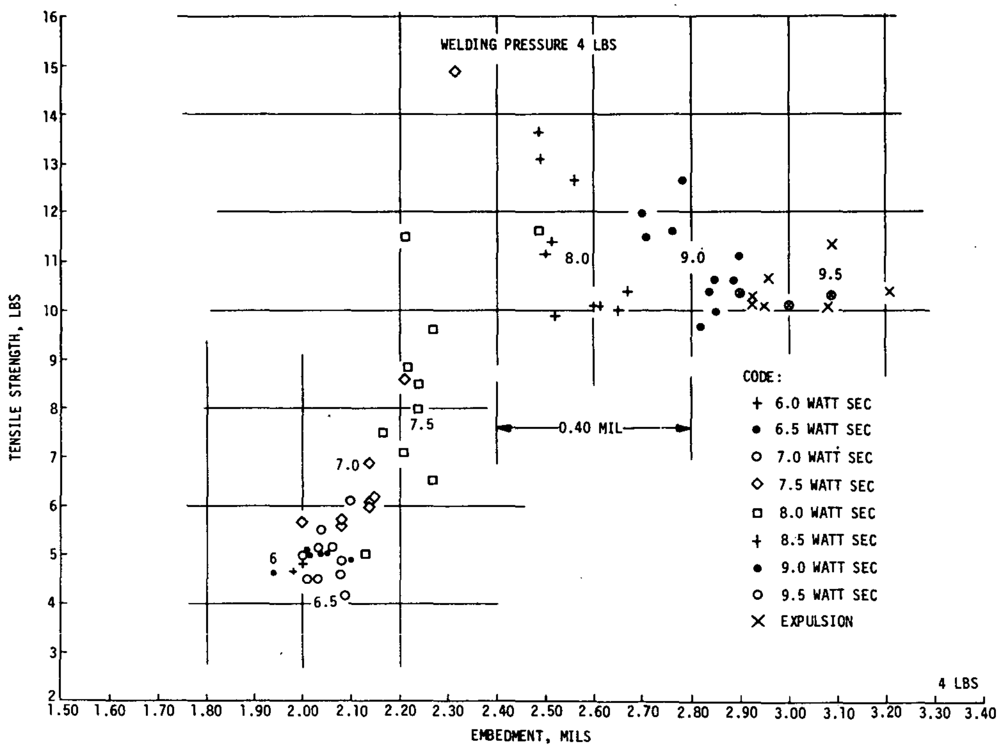


Figure A-2. Correlation of Tensile Strength with Embedment 0.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

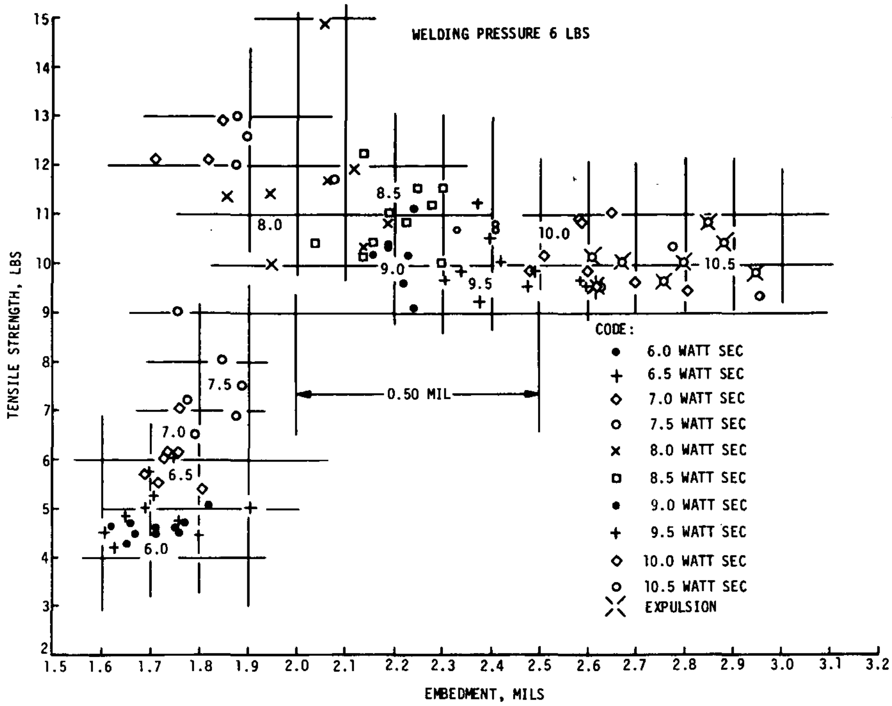


Figure A-3. Correlation of Tensile Strength with Embedment
0.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

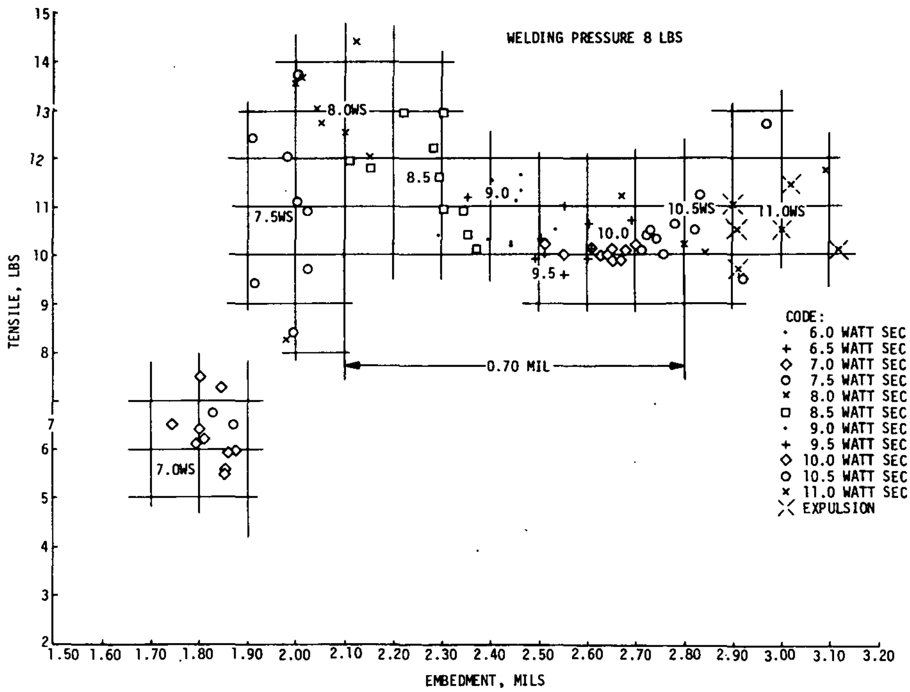


Figure A-4. Correlation of Tensile Strength with Embedment
0.020 Diameter Dumet (Au) to 0.010 x 0.032 Ni

APPENDIX B

CORRELATION OF TENSILE STRENGTH WITH EMBEDMENT

0.020 Diameter Dumet (Au) to 0.020 Diameter Alloy 180

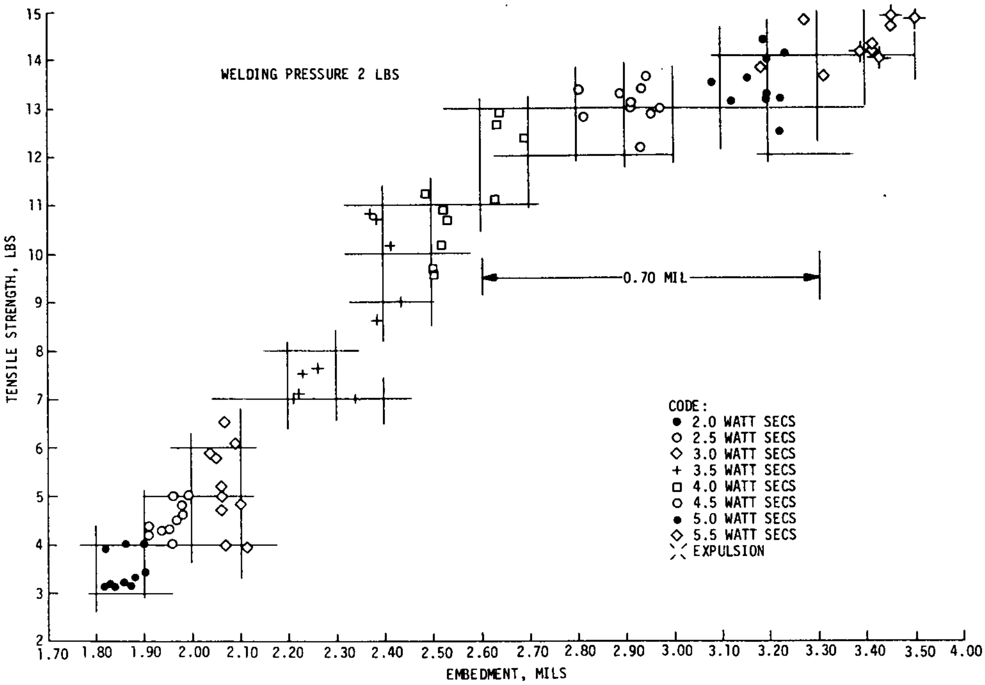


Figure B-1. Correlation of Tensile Strength with Embedment
0.020 Dumet (Au) to 0.020 Alloy 180

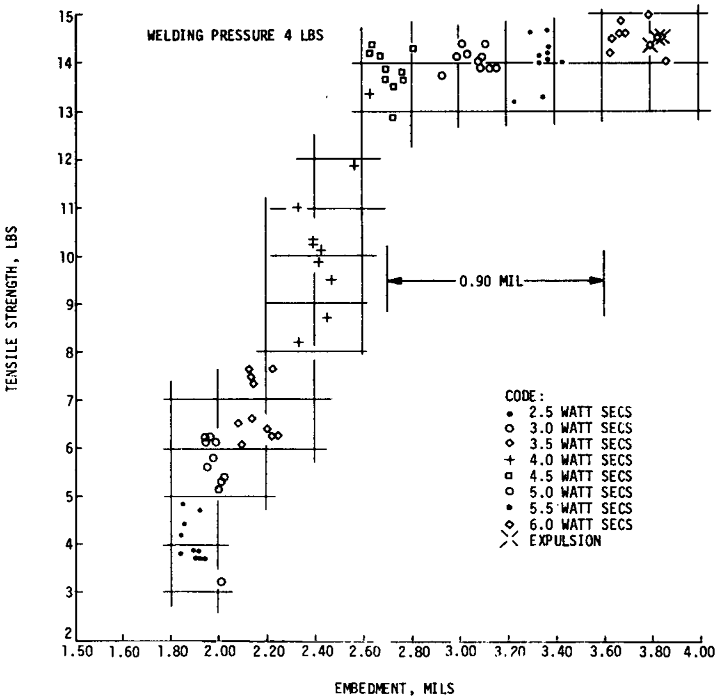


Figure B-2. Correlation of Tensile Strength with Embedment
0.020 Dumet (Au) to 0.020 Alloy 180

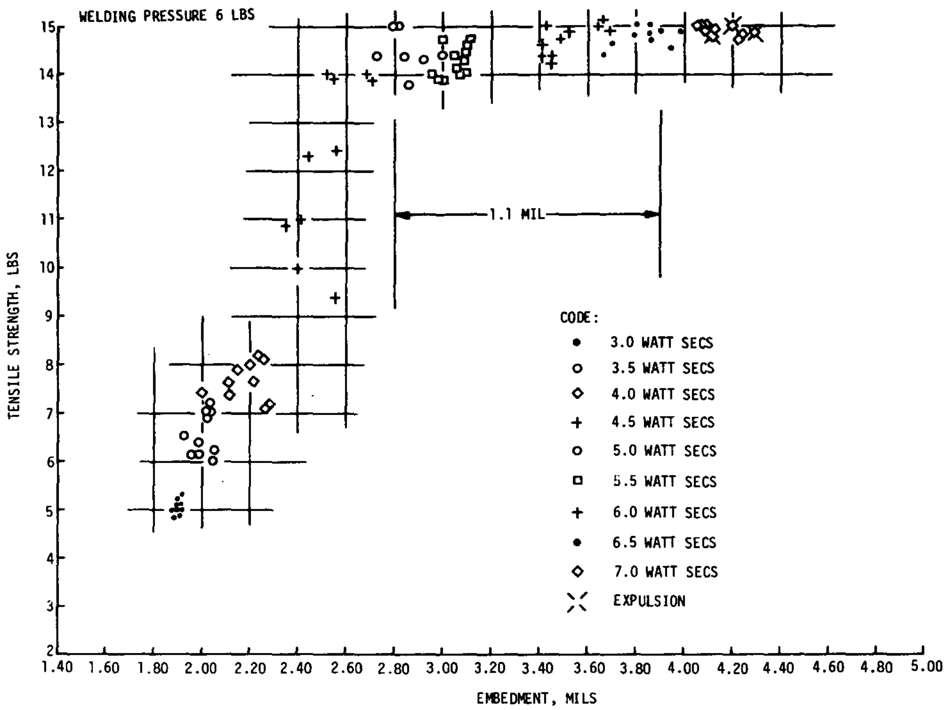


Figure B-3. Correlation of Tensile Strength with Embedment
0.020 Dumet (Au) to 0.020 Alloy 180

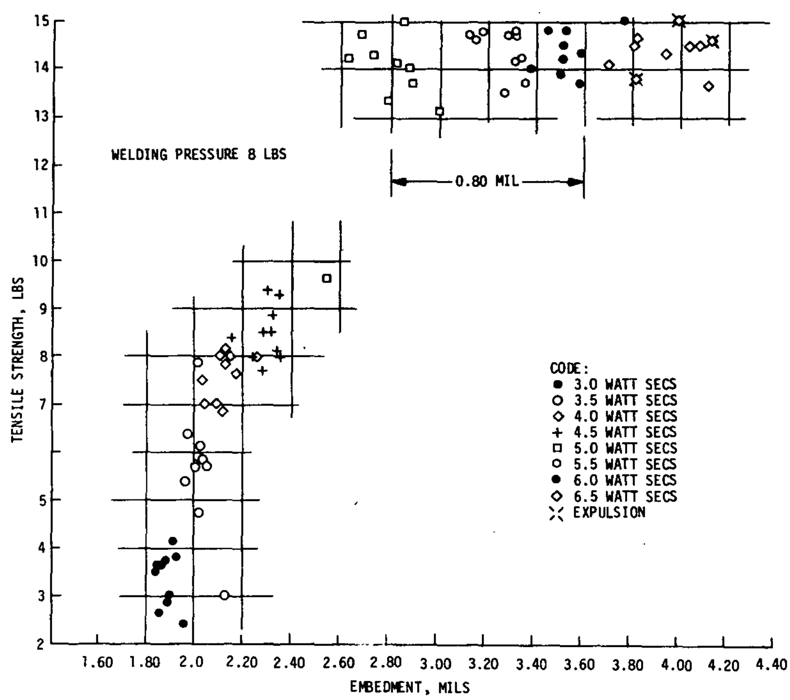


Figure B-4. Correlation of Tensile Strength with Embedment
0.020 Dumet (Au) to 0.020 Alloy 180

APPENDIX C

CORRELATION OF TENSILE STRENGTH WITH EMBEDMENT

0.017 Diameter Kovar (Au) to 0.010 x 0.032 Ni

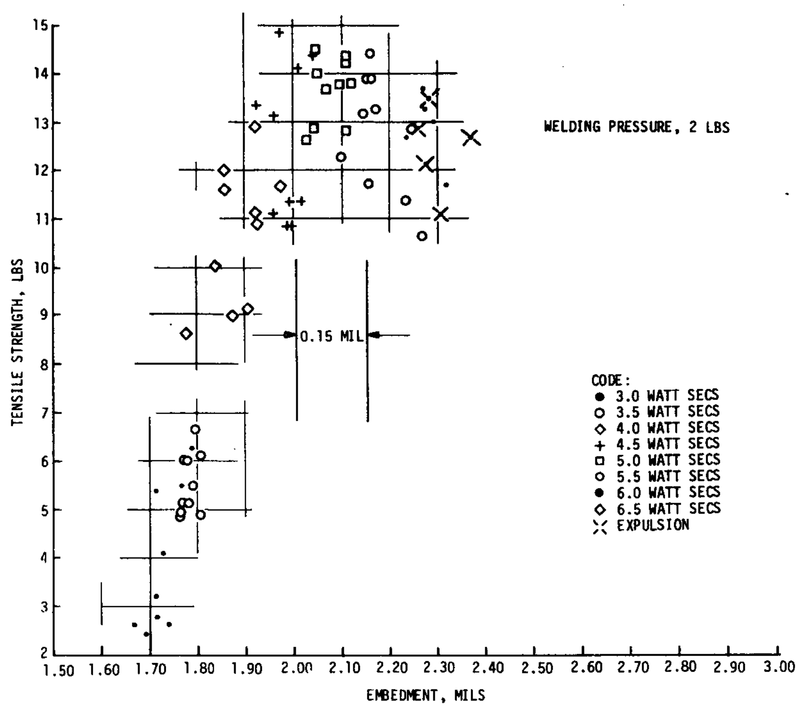


Figure C-1. Correlation of Tensile Strength with Embedment 0.017 Kovar (Au) to 0.010 x 0.032 Ni

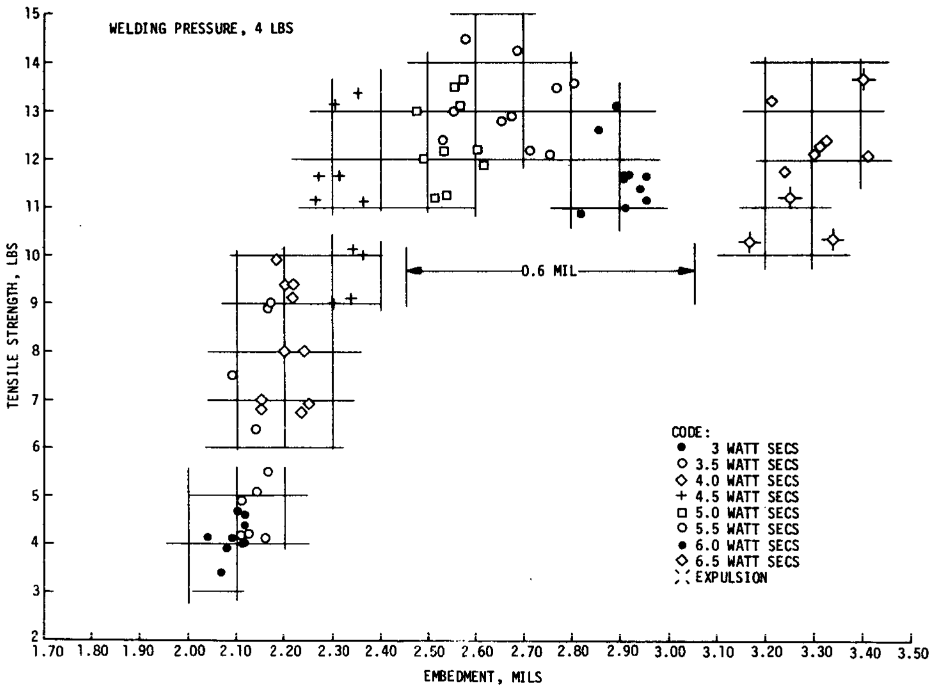


Figure C-2. Correlation of Tensile Strength with Embedment 0.017 Kovar (Au) to 0.010 x 0.032 Ni

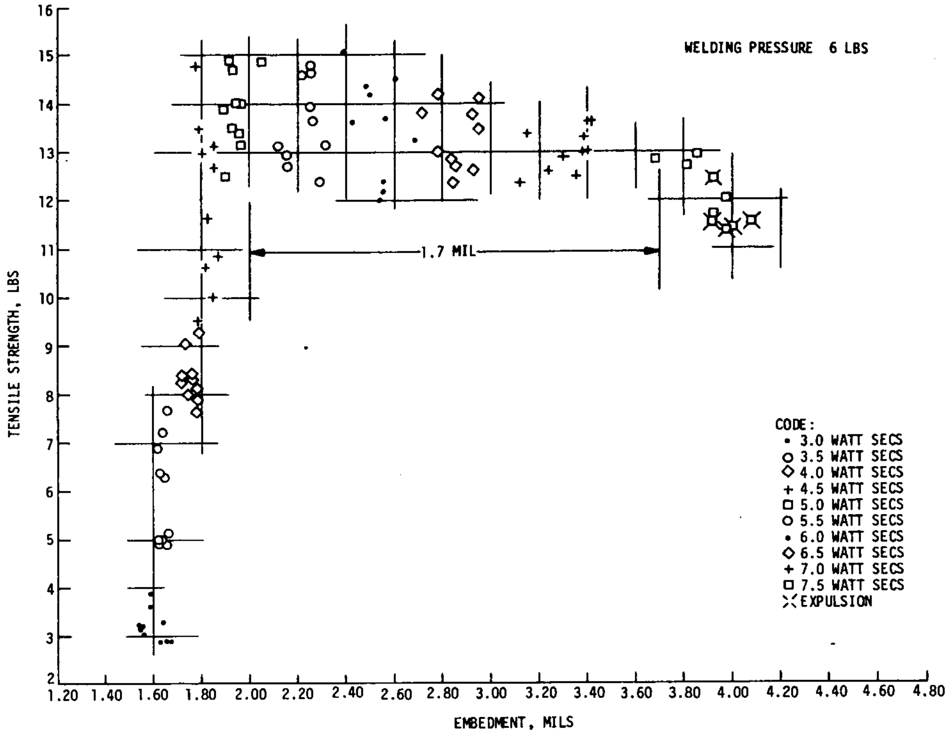


Figure C-3. Correlation of Tensile Strength with Embedment 0.017 Kovar (Au) to 0.010 x 0.032 Ni

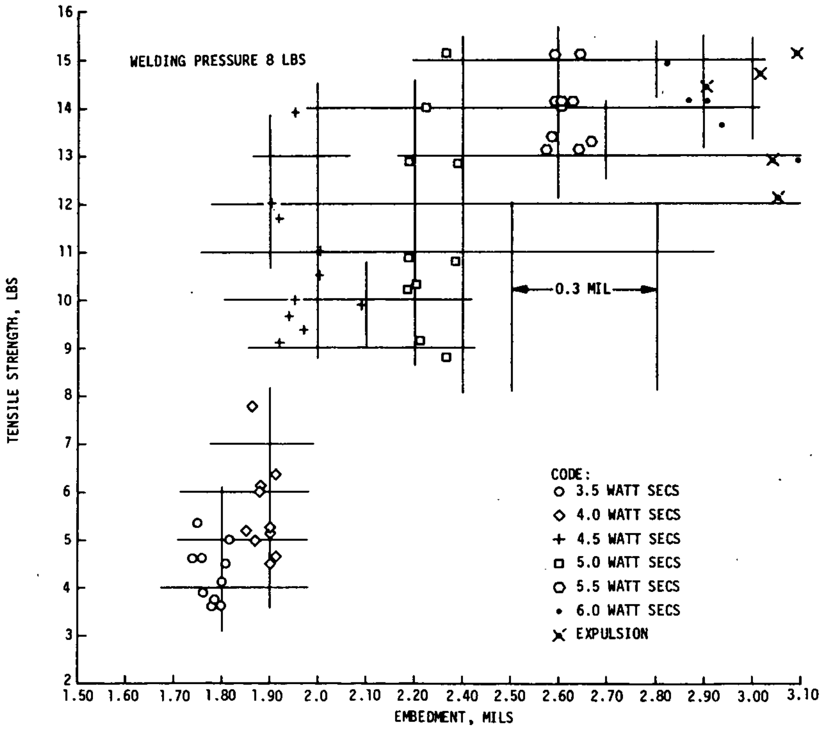


Figure C-4. Correlation of Tensile Strength with Embedment 0.017 Kovar (Au) to 0.010 x 0.032 Ni

APPENDIX D

CORRELATION OF TENSILE STRENGTH WITH EMBEDMENT

0.017 Diameter Kovar (Au) to 0.020 Diameter Alloy 180

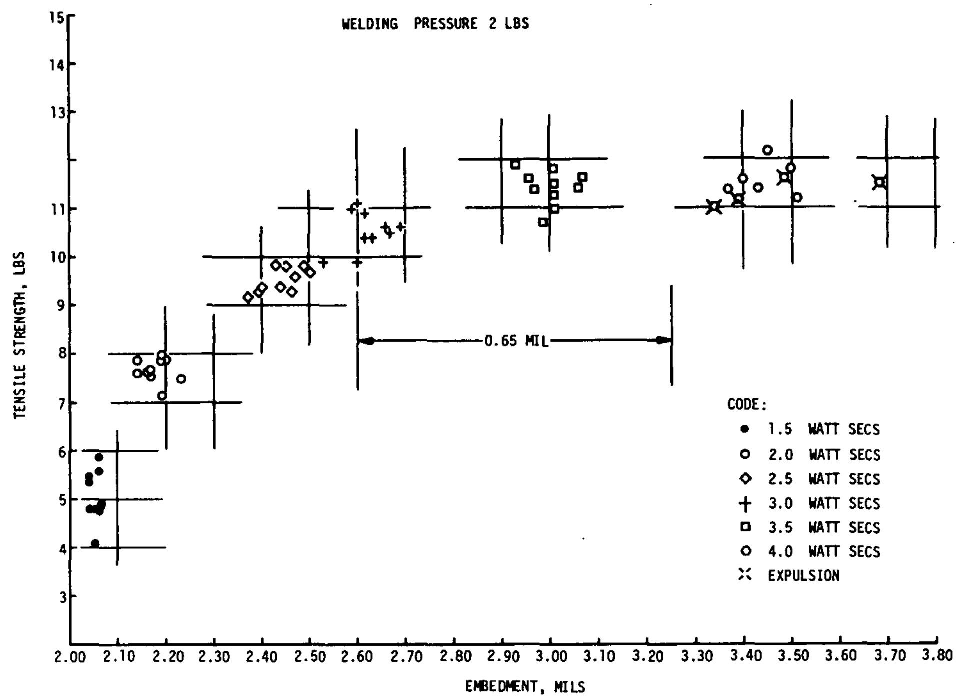


Figure D-1. Correlation of Tensile Strength with Embedment 0.017 Kovar to 0.020 Alloy 180

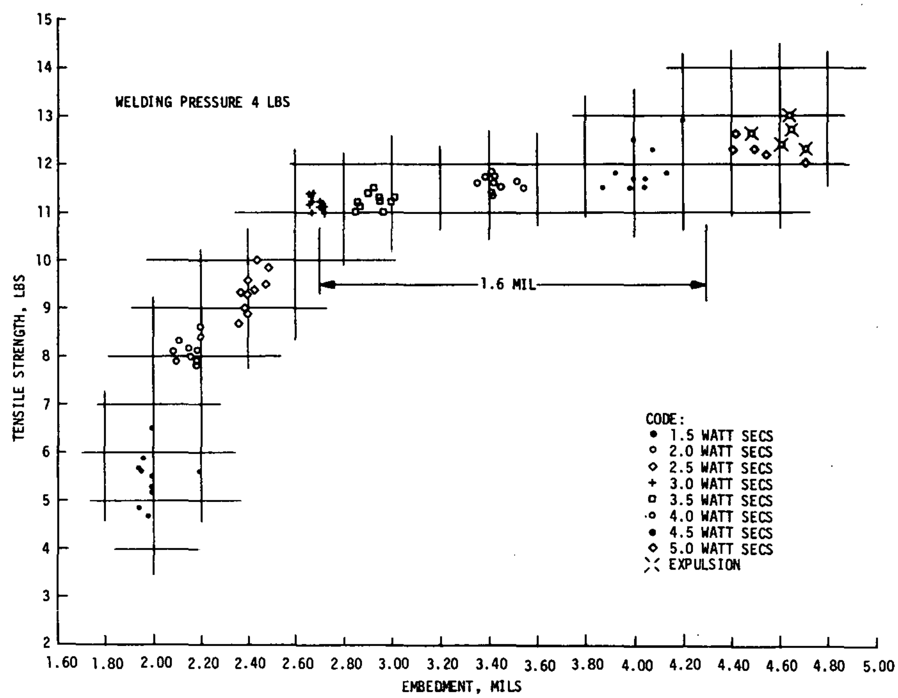


Figure D-2. Correlation of Tensile Strength with Embedment 0.017 Kovar to 0.020 Alloy 180

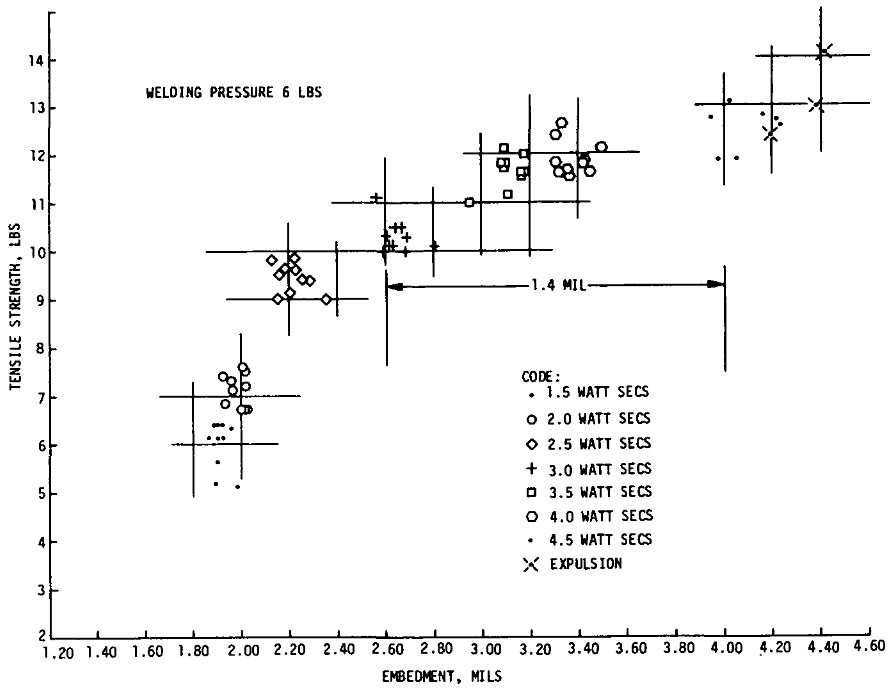
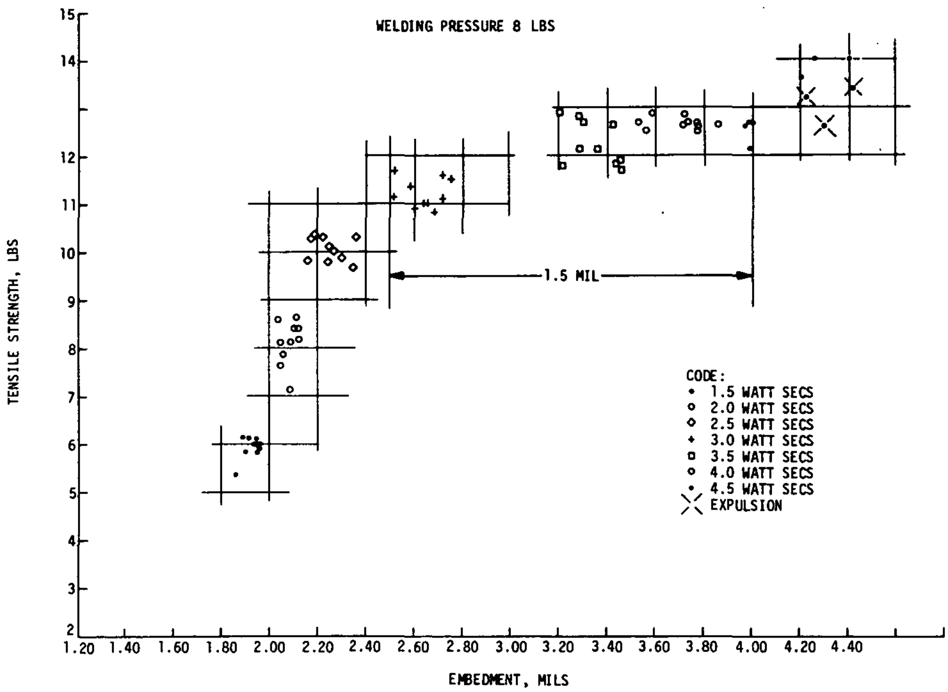


Figure D-3. Correlation of Tensile Strength with Embedment
0.017 Kovar to 0.020 Alloy 180



igure D-4. Correlation of Tensile Strength with Embedment
0.017 Kovar to 0.020 Alloy 180

APPENDIX E

TEST DATA FOR THREE REGION SEPARATION AND STATISTICAL ANALYSIS

TABLE E-I

Dumet (Au)/Ni Ribbon
Weld Schedule and Test Data

Low Strength Region

Material: **Positive Side** .020 Dumet (Au) **Neg. Side** .010 x .032 Ni
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 7.75 W/s **Pressure** 81 lb

Sample	Embedment	Pull
1	182	5.8 L
2	192	10.4
3	190	12.9 H
4	191	11.6
5	182	6.5 L
6	187	7.5
7	197	9.6
8	189	8.2
9	195	12.1
10	192	5.6 L
11	H 204	12.2
12	195	11.6
13	195	12.2
14	H 202	12.3
15	196	11.5
16	H 213	12.8
17	201	11.0
18	196	12.6
19	185	9.7
20	184	12.4
21	L 178	7.4
22	187	9.5
23	L 181	7.6
24	196	13.5
25	195	12.9 H
26	185	7.4
27	H 205	8.6
28	188	7.9
29	190	10.2
30	195	11.3
31	195	9.5
32	182	6.8
33	182	11.4
34	200	10.4
35	198	12.9 H
36	H 205	12.7
37	190	7.2
38	194	9.7
39	187	8.7
40	L 177	7.9
41	188	11.4
42	188	11.0
43	189	7.2
44	182	12.4
45	185	13.2 H
46	L 177	8.7
47	186	12.4
48	184	13.0 H
49	L 168	5.2 L
50	182	6.4 L

Pull Strength

$n = 50$

$\Sigma X^2 = 5343.55$

$\Sigma X = 502.9$

$\frac{\Sigma X^2}{n} = 106.871$

$\bar{X} = \frac{\Sigma X}{n} = 10.0580$

$\bar{X}^2 = 101.163364$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{5.708} = 2.39$

$\sigma u = 2.4$

Embedment

$n = 50$

$\Sigma X^2 = 181.1231$

$\Sigma X = 95.07$

$\frac{\Sigma X^2}{n} = 3.622462$

$\bar{X} = \frac{\Sigma X}{n} = 1.9014$

$\bar{X}^2 = 3.61532196$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.00714} = .0845$

$\sigma u = 0.0853$

$3.126\ \sigma u = 0.267$

Limits $\bar{X} \pm 3.126\ \sigma u$

$= 1.63$ to 2.17

Coefficient of Variance

Pull Strength: $\frac{\sigma u}{\bar{X}} = .045$

Embedment: $\frac{\sigma u}{\bar{X}} = .24$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-II

Dumet (Au)/Ni Ribbon
Weld Schedule and Test Data

Optimum Weld Region

Material: Positive Side .020 Dumet (Au) **Neg. Side** .010 x .032Ni
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 10.0 **Pressure** 8.0

Sample	Embedment	Pull
1	L 246	9.9
2	261	10.7
3	264	10.0
4	253	9.8 L
5	269	10.7
6	256	9.8 L
7	267	10.8
8	L 245	9.5 L
9	H 270	11.0
10	H 271	10.8
11	262	9.9
12	255	10.0
13	L 246	10.8
14	261	9.9
15	268	11.2 H
16	257	10.0
17	251	10.2
18	261	9.8 L
19	H 270	11.1 H
20	269	10.6
21	262	10.2
22	L 245	11.0
23	264	10.0
24	249	9.9
25	H 271	10.2
26	255	9.6 L
27	254	10.9
28	264	10.9
29	256	10.0
30	L 241	9.6
31	247	10.1
32	H 270	12.1 H
33	251	9.5 L
34	253	9.8
35	250	9.9
36	261	10.0
37	266	11.1 H
38	249	9.8
39	251	10.6
40	266	10.1
41	247	9.9
42	252	10.8
43	256	10.7
44	268	9.5
45	250	10.5
46	251	10.3
47	267	10.5
48	255	10.2
49	252	10.3
50	261	11.4 H

Pull Strength

$n = 50$

$\Sigma X^2 = 5338.79$

$\Sigma X = 5159$

$\frac{\Sigma X^2}{n} = 106.7758$

$\bar{X} = \frac{\Sigma X}{n} = 10.318$

$\bar{X}^2 = 106.4611$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.3147} = 0.561$

$3\sigma = 0.57$

Embedment

$n = 50$

$\Sigma X^2 = 332.4484$

$\Sigma X = 128.86$

$\frac{\Sigma X^2}{n} = 6.648968$

$\bar{X} = \frac{\Sigma X}{n} = 2.5772$

$\bar{X}^2 = 6.64195984$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.00701} = .084, \sigma u = .085$

$3.126\ \sigma u = 0.264$

Limit $\bar{X} \pm 3.126\ \sigma u$
$= 2.31$ to 2.84

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .055$ $\frac{\sigma u}{\bar{X}} = .033$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-III

Dumet (Au)/Ni Ribbon
Weld Schedule and Test Data

Overheated Weld Region

Material: **Positive Side** .020 Dumet (Au) **Neg. Side** .010 x .032 Ni
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 10.75 **Pressure** 8

Sample		Embedment	Pull	
1		280	9.6	L
2		274	11.0	
3		287	10.3	
4		278	10.0	
5	H E	301	10.4	
6		274	11.1	
7		277	10.1	
8		282	10.0	
9	E	291	10.4	
10		279	9.9	L
11		290	10.3	
12		277	11.1	
13		278	10.9	
14		280	11.2	
15		292	11.5	H
16	L	270	10.4	
17		291	10.1	
18	H	281	10.4	
19	E	315	11.7	
20	L	271	10.2	
21		286	11.4	H
22		279	11.2	
23	H	303	11.0	
24		294	11.9	H
25		298	11.1	
26		272	10.5	
27		278	11.2	
28		279	10.4	
29		274	10.3	
30	E	289	10.6	
31	L	269	10.0	
32	H E	303	12.0	H
33		298	11.9	H
34	L	266	9.8	L
35		275	11.0	
36		277	10.3	
37		278	9.1	L
38	E	280	10.2	
39		281	9.9	L
40		282	10.5	
41		287	10.9	
42		281	10.0	
43	H	308	11.2	
44		274	10.0	
45	E	274	11.0	
46		296	10.9	
47		297	11.1	
48		274	10.6	
49	L	267	10.9	
50		289	11.3	

Pull Strength

$n = 50$

$\Sigma X^2 = 5697.36$

$\Sigma X = 532.8$

$\frac{\Sigma X^2}{n} = 113.9472$

$\bar{X} = \frac{\Sigma X}{n} = 10.656$

$\bar{X}^2 = 113.5503$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.3969} = 0.6300$

$3\sigma u = 0.64$

Embedment

$n = 50$

$\Sigma X^2 = 402.5268$

$\Sigma X = 141.76$

$\frac{\Sigma X^2}{n} = 8.0505360$

$\bar{X} = \frac{\Sigma X}{n} = 2.83520$

$\bar{X}^2 = 8.03835904$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.01218} = .110, \sigma u = .111$

$3.126\ \sigma u = 0.333$

Limits $\bar{X} \pm 3.126\ \sigma u$
2.5 to 3.2

Coefficient of Variance

Pull Strength: $\frac{\sigma u}{\bar{X}} = .059$

Embedment: $\frac{\sigma u}{\bar{X}} = .039$

Code:

H – One of 5 high data
L – One of 5 low data
E – Expulsion

TABLE E-IV

Dumet (Au)/Alloy 180
Weld Schedule and Test Data

Low Strength Region

Material: Positive Side .020 Dumet (Au) **Neg. Side** .020 Alloy 180
Electrodes: Top No. No. 2 Bottom No. No. 2 **Machine** HRW100 Head VTA60
Heat 4.5 Pressure 6

Sample	Embed-ment	Pull
1	239	7.2 L
2	246	11.4
3	242	9.4
4	241	9.9
5	248	7.0 L
6	H 269	14.5
7	257	14.1
8	240	8.9
9	258	14.6 H
10	253	8.8
11	271	13.8
12	238	8.4
13	262	14.4
14	242	8.4
15	L 236	8.9
16	237	11.0
17	242	13.4
18	258	14.5
19	H 264	15.0 H
20	232	9.0
21	245	14.4
22	L 235	8.3 L
23	238	8.2 L
24	L 236	9.0
25	H 267	14.5
26	257	14.5
27	248	14.8 H
28	261	15.0 H
29	H 265	12.9
30	259	14.4
31	250	14.6 H
32	254	8.6
33	257	14.2
34	247	13.8
35	245	14.1
36	244	13.9
37	252	13.8
38	238	9.7
39	L 236	8.5
40	242	13.1
41	L 234	9.0
42	H 265	14.0
43	242	11.9
44	251	14.2
45	L 236	10.0
46	255	14.5
47	239	9.5
48	248	13.6
49	243	10.4
50	239	8.1

Pull Strength

$n = 50$

$\Sigma X^2 = 727016$

$\Sigma X = 5880$

$\frac{\Sigma X^2}{n} = 145.4032$

$\bar{X} = \frac{\Sigma X}{n} = 11.76$

$\bar{X}^2 = 138.2976$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{7.11} = 2.67$

$\sigma u = 2.7$

Embedment

$n = 50$

$\Sigma X^2 = 308.2139$

$\Sigma X = 124.03$

$\frac{\Sigma X^2}{n} = 6.16427$

$\bar{X} = \frac{\Sigma X}{n} = 2.48$

$\bar{X}^2 = 6.15337$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.010902} = 0.104, \quad \sigma u = .105$

$3.126\ \sigma u = 0.31$

Limit $\bar{X} \pm 3.126\ \sigma u$

2.15 to 2.81

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .23$ $\frac{\sigma u}{\bar{X}} = .042$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-V

Dumet (Au)/Alloy 180
Weld Strength and Test Data

Optimum Weld Region

Material: **Positive Side** .020 Dumet (Au) **Neg. Side** .020 Alloy 180
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 5.75 **Pressure** 6

Sample	Embed-ment	Pull
1	319	14.9 H
2	319	14.9 H
3	L 314	15.1 H
4	L 310	14.7
5	333	14.5
6	318	14.8
7	322	14.8
8	320	15.2 H
9	326	14.6
10	335	14.3
11	H 341	13.7 L
12	L 317	14.4
13	H 344	14.5
14	326	14.4
15	H 336	14.2 L
16	321	14.0
17	332	14.3
18	320	14.9 H
19	321	14.6
20	326	14.5
21	332	14.8
22	319	14.5
23	333	14.7
24	321	13.9 L
25	H 336	14.4
26	324	14.3
27	320	14.7
28	319	14.6
29	331	14.6
30	L 318	14.5
31	321	14.6
32	334	14.8
33	330	14.8
34	333	14.9 H
35	H 340	14.7
36	H 338	14.4
37	321	14.6
38	329	14.6
39	323	14.5
40	324	14.7
41	330	14.2 L
42	319	14.8
43	329	14.4
44	322	14.5
45	320	14.4
46	319	14.1 L
47	L 313	14.6
48	333	14.6
49	335	14.4
50	324	14.5

Pull Strength

$n = 50$

$\Sigma X^2 = 1058620$

$\Sigma X = 7274$

$\frac{\Sigma X^2}{n} = 211.724$

$\bar{X} = \frac{\Sigma X}{n} = 14.548$

$\bar{X}^2 = 211.644$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.08} = .28$

$\sigma u = .283$

Embedment

$n = 50$

$\Sigma X^2 = 530.3912$

$\Sigma X = 162.80$

$\frac{\Sigma X^2}{n} = 10.60782$

$\bar{X} = \frac{\Sigma X}{n} = 3.256$

$\bar{X}^2 = 10.60154$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.006288} = 793$, $\sigma u = 0.08$

$3.126\ \sigma u = 0.250$

Limit $\bar{X} \pm 3.126\ \sigma u$
3.0 to 3.5

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .02$ $\frac{\sigma u}{\bar{X}} = .025$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-VI

Dumet (Au)/Alloy 180
Weld Strength and Test Data

Overheated Weld Region

Material: **Positive Side** .020 Dumet (Au) **Neg. Side** .020 Alloy 180
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 7.0 **Pressure** 6

Sample	Embed-ment	Pull
1	418	14.8
2	413	14.9
3	426	14.5 L
4	E 430	14.6
5	E 435	14.7
6	411	14.7
7	424	15.1 H
8	420	14.5
9	413	14.8
10	E 435	15.0
11	424	14.9
12	430	14.8
13	417	14.8
14	422	14.9
15	413	15.0
16	421	14.7
17	E 435	14.7
18	E 421	14.8
19	430	14.9
20	426	15.0
21	419	14.6
22	430	14.7
23	422	14.9
24	418	14.7
25	417	14.8
26	428	14.7
27	426	15.1 H
28	E 430	14.3 L
29	422	14.6
30	415	14.7
31	408	14.8
32	419	15.0
33	E 421	15.2 H
34	432	15.0
35	412	15.3 H
36	E 439	14.9
37	428	14.4 L
38	E 430	15.0
39	419	14.7
40	420	14.8
41	424	14.7
42	430	15.1 H
43	427	14.4 L
44	422	14.8
45	416	15.0
46	419	14.3 L
47	E 428	14.7
48	433	14.6
49	422	14.7
50	419	14.9

Pull Strength

$n = 50$

$\Sigma X^2 = 10939.51$

$\Sigma X = 73.95$

$\frac{\Sigma X^2}{n} = 218.790$

$\bar{X} = \frac{\Sigma X}{n} = 14.79$

$\bar{X}^2 = 218.741$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.049} = 22$

$\sigma u = .22$

Embedment

$n = 50$

$\Sigma X^2 = 896.078$

$\Sigma X = 211.64$

$\frac{\Sigma X^2}{n} = 17.92156$

$\bar{X} = \frac{\Sigma X}{n} = 4.23$

$\bar{X}^2 = 17.9166$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.004964} = .07046, \sigma u = .0711$

$3.126\ \sigma u = .22$

Limit $\bar{X} \pm 3.126$
4.01 to 4.45

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .015$ $\frac{\sigma u}{\bar{X}} = .017$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-VII

Kovar (Au)/Ni Ribbon
Weld Schedule and Test Data

Low Strength Region

Material: Positive Side .017 Kovar (Au) **Neg. Side** .010 x .032 Ni
Electrodes: Top No. No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 4.5 **Pressure** 6

Sample	Embed-ment	Pull
1	195	10.9
2	196	8.5 L
3	195	11.5
4	200	11.5
5	198	8.8 L
6	194	10.6
7	190	11.3
8	196	9.5
9	198	10.6
10	189	10.5
11	190	11.9
12	194	10.9
13	189	8.9 L
14	196	12.2
15	H 201	13.1 H
16	191	10.5
17	188	10.5
18	198	8.1 L
19	L 186	10.4
20	189	10.3
21	193	9.9
22	193	12.6
23	L 187	11.7
24	198	13.0 H
25	195	11.3
26	191	9.0
27	192	9.2
28	190	10.7
29	195	10.5
30	188	11.6
31	195	11.3
32	190	13.4 H
33	198	8.9 L
34	H 200	10.7
35	192	9.4
36	L 188	11.4
37	L 187	11.7
38	194	13.5 H
39	196	10.1
40	H 201	9.4
41	191	10.4
42	189	9.5
43	194	9.0
44	H 202	12.0
45	H 200	10.0
46	201	9.8
47	192	9.8
48	191	10.0
49	L 186	14.0 H
50	193	11.9

Pull Strength

$n = 50$

$\Sigma X^2 = 584352$

$\Sigma X = 5362$

$\frac{\Sigma X^2}{n} = 116870$

$\bar{X} = \frac{\Sigma X}{n} = 10.724$

$\bar{X}^2 = 115.004$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{1.866} = 1.366$

$\sigma u = 1.38$

Embedment

$n = 50$

$\Sigma X^2 = 187.3069$

$\Sigma X = 96.75$

$\frac{\Sigma X^2}{n} = 3.7461480$

$\bar{X} = \frac{\Sigma X}{n} = 1.93500$

$\bar{X}^2 = 3.74423$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.001913} = 04.3738, \sigma u = 0.0442$

$3.126\ \sigma u = 0.1381$

Limit $\bar{X} \pm 3.126\ \sigma u$
1.80 to 2.07

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .13$ $\frac{\sigma u}{\bar{X}} = .023$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-VIII

Kovar (Au)/Ni Ribbon
Weld Schedule and Test Data

Optimum Weld Region

Material: **Positive Side** .017 Kovar (Au) **Neg. Side** .010 x .032 Ni
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 6.25 **Pressure** 6

Sample	Embed-ment	Pull
1	287	13.4
2	293	13.2
3	L 273	14.5
4	284	13.1
5	290	14.6
6	296	13.0
7	L 274	14.0
8	295	11.8 L
9	282	14.4
10	292	12.1
11	287	11.5 L
12	287	13.0
13	L 275	13.2
14	L 226	14.7
15	291	15.1 H
16	H 300	13.2
17	288	14.8
18	H 299	12.4
19	292	11.9 L
20	L 274	14.1
21	277	13.5
22	288	12.5
23	H 301	14.7
24	290	12.6
25	285	12.5
26	288	12.2
27	292	13.1
28	282	12.6
29	294	13.7
30	296	11.9
31	290	12.4
32	291	13.4
33	294	13.2
34	289	14.9 H
35	284	13.8
36	290	13.0
37	293	13.9
38	288	14.0
39	284	13.4
40	299	14.0
41	283	13.9
42	286	11.5 L
43	H 302	12.9
44	291	13.4
45	291	11.6 L
46	299	14.5
47	282	13.5
48	284	15.2 H
49	H 303	14.9 H
50	299	14.0 H

Pull Strength

$n = 50$

$\Sigma X^2 = 901932$

$\Sigma X = 6696$

$\frac{\Sigma X^2}{n} = 180.3864$

$\bar{X} = \frac{\Sigma X}{n} = 13.392$

$\bar{X}^2 = 179.3457$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{1.0407} = 1.020$

$\sigma u = 1.03$

Embedment

$n = 50$

$\Sigma X^2 = 417.8882$

$\Sigma X = 144.50$

$\frac{\Sigma X^2}{n} = 8.35776$

$\bar{X} = \frac{\Sigma X}{n} = 2.890$

$\bar{X}^2 = 8.35210$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.00566} = 0.0753, \sigma u = 0.076$

$3.126\ \sigma u = .238$

Limit $\bar{X} \pm 3.126\ \sigma u$
2.65 to 3.13

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .077$ $\frac{\sigma u}{\bar{X}} = .026$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-IX

Kovar (Au)/Ni Ribbon
Weld Schedule and Test Data

Overheated Weld Region

Material: **Positive Side** .017 Kovar (Au) **Neg. Side** .010 x .032 Ni
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 7.5 **Pressure** 6

Sample	Embedment	Pull
1	420	12.4
2	408	12.1
3	405	11.5
4	427	11.7
5	SP 404	11.0 L
6	400	13.3
7	HSP 430	12.0
8	L 396	13.1
9	SP 415	12.9
10	408	13.2
11	408	12.4
12	SP 415	11.5
13	L 392	11.1 L
14	L 390	14.0 H
15	407	11.8
16	H 437	12.5
17	SP 413	13.2
18	406	12.4
19	SP 398	13.5
20	SP 415	13.2
21	416	12.7
22	410	12.4
23	SP 400	11.2 L
24	SP 411	13.5 H
25	H 428	12.1
26	L 394	13.8 H
27	424	13.0
28	413	13.0
29	400	12.4
30	407	13.5
31	SP 419	10.6 L
32	405	12.4
33	403	12.2
34	H 438	12.0
35	418	13.1
36	411	12.9
37	415	10.5 L
38	424	11.5
39	408	12.3
40	L 390	12.6
41	404	12.3
42	412	14.0 H
43	HSP 430	12.7
44	SP 410	12.9
45	397	12.4
46	SP 421	12.3
47	413	11.3
48	407	11.9
49	400	14.3 H
50	420	12.2

Pull Strength

$n = 50$

$\Sigma X^2 = 779446$

$\Sigma X = 6228$

$\frac{\Sigma X^2}{n} = 155.889$

$\bar{X} = \frac{\Sigma X}{n} = 12.456$

$\bar{X}^2 = 155152$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.737} = .858$

$\sigma u = .864$

Embedment

$n = 50$

$\Sigma X^2 = 844.1532$

$\Sigma X = 205.42$

$\frac{\Sigma X^2}{n} = 16.88306$

$\bar{X} = \frac{\Sigma X}{n} = 4.108$

$\bar{X}^2 = 16.87895$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.004114} = .064, \sigma u = .065$

$3.126\ \sigma u = .202$

Limit $\bar{X} \pm 3.126\ \sigma u$
3.91 to 4.32

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .069$ $\frac{\sigma u}{\bar{X}} = .016$

Code:

H – One of 5 high data
L – One of 5 low data
SP – Spit

TABLE E-X

Kovar (Au)/Alloy 180
Weld Schedule and Test Data

Low Strength Region

Material: Positive Side .017 Kovar (Au) Neg. Side .020 Alloy 180
Electrodes: Top No. No. 2 Bottom No. No.2 Machine Hughes HRW100 Head VTA60
Heat 2.45 **Pressure** 4 lb

Sample	Embedment	Pull
1	223	8.7
2	228	8.5
3	223	9.0
4	H 236	9.0
5	231	8.6
6	225	8.9
7	H 233	8.6
8	219	9.1
9	225	9.0
10	230	9.1
11	H 232	8.9
12	228	9.1
13	H 237	8.4
14	225	9.8
15	228	9.4 H
16	225	9.1
17	227	9.1
18	229	8.4 L
19	227	8.5
20	221	9.0
21	230	8.9
22	227	8.4
23	227	8.0 L
24	L 218	9.3 H
25	231	8.5
26	219	9.1
27	H 217	9.1
28	228	9.1
29	218	7.8 L
30	228	8.9
31	H 239	8.7
32	230	9.0
33	227	8.5
34	228	8.7
35	220	8.9
36	228	9.2
37	225	8.9
38	L 212	9.4 H
39	224	9.0
40	220	9.0
41	230	9.5 H
42	225	8.4 L
43	222	8.9
44	L 216	9.3 H
45	229	8.9
46	228	8.0
47	228	8.3 L
48	219	9.0
49	227	9.0
50	L 210	9.1

Pull Strength

$n = 50$

$\Sigma X^2 = 3932.56$

$\Sigma X = 443.0$

$\frac{\Sigma X^2}{n} = 78.6512$

$\bar{X} = \frac{\Sigma X}{n} = 8.86$

$\bar{X}^2 = 78.4996$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.1514} = .389$

$\sigma u = .393$

Embedment

$n = 50$

$\Sigma X^2 = 254.7362$

$\Sigma X = 112.82$

$\frac{\Sigma X^2}{n} = 5.09472$

$\bar{X} = \frac{\Sigma X}{n} = 2.2564$

$\bar{X}^2 = 5.09134$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.003383} = 0.05816, \sigma u = 0.059$

$3.126\ \sigma u = .184$

Limit $\bar{X} \pm 3.126\ \sigma u$
2.07 to 2.44

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .044$ $\frac{\sigma u}{\bar{X}} = .026$

Code:

H – One of 5 high data
L – One of 5 low data

2(8)

TABLE E-XI

Kovar (Au)/Alloy 180
Weld Schedule and Test Data

Optimum Weld Region

Material: **Positive Side** .017 Kovar (Au) **Neg. Side** .020 Alloy 180
Electrodes: **Top No.** No. 2 **Bottom No.** No. 2 **Machine** HRW100 **Head** VTA60
Heat 3.75 **Pressure** 4 lb

Sample	Embedment	Pull
1	H 324	11.9
2	314	11.9
3	315	11.6
4	317	11.6
5	310	11.4 L
6	315	11.6
7	309	11.5
8	H 325	11.4
9	321	11.7
10	H 323	11.4
11	318	11.8
12	310	11.5
13	313	11.5
14	310	11.1 L
15	311	12.0
16	316	12.0 H
17	318	12.6 H
18	310	11.6
19	310	11.8
20	318	11.5
21	H 323	11.4
22	L 307	12.1 H
23	316	11.0
24	309	11.8
25	314	11.4
26	H 328	11.9
27	314	11.9
28	315	11.7
29	312	12.2 H
30	321	11.1 L
31	L 306	11.1 L
32	322	11.4
33	318	11.9
34	312	12.3 H
35	321	11.7
36	310	11.8
37	311	11.9
38	311	11.6
39	312	11.9
40	314	11.4 L
41	308	11.6
42	315	12.0
43	315	11.9
44	319	11.5
45	L 306	11.9
46	L 307	11.9
47	309	11.6
48	318	11.7
49	312	11.7
50	L 307	11.7

Pull Strength

$n = 50$

$\Sigma X^2 = 683522$

$\Sigma X = 5844$

$\frac{\Sigma X^2}{n} = 136704$

$\bar{X} = \frac{\Sigma X}{n} = 11.68$

$\bar{X}^2 = 136.422$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.282} = .53$

$\sigma u = .54$

Embedment

$n = 50$

$\Sigma X^2 = 494.2860$

$\Sigma X = 157.18$

$\frac{\Sigma X^2}{n} = 9.88572$

$\bar{X} = \frac{\Sigma X}{n} = 3.1436$

$\bar{X}^2 = 9.88222$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.0035} = .0592, \sigma u = .060$

$3.126\ \sigma u = 0.187$

Limit $\bar{X} \pm 3.126\ \sigma u$
2.96 to 3.33

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = .046$ $\frac{\sigma u}{\bar{X}} = .019$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE E-XII

Kovar (Au)/Alloy 180
Weld Schedule and Test Data

Overheated Weld Region

Material: **Positive Side** .017 Kovar (Au) **Neg. Side** .020 Alloy 180
Electrodes: **Top No.** No. 2 **Bottom No.** No.2 **Machine** HRW100 **Head** VTA60
Heat 4.75 **Pressure** 4 lb

Sample		Embed-ment	Pull	
1		437	12.5	
2	SP	H 455	12.8	
3		446	12.2	L
4		437	12.7	
5		431	13.0	
6		431	12.3	
7	SP	434	11.9	L
8		436	13.9	H
9		439	12.4	
10		L 426	12.4	
11	SP	433	12.5	
12		L 427	12.2	L
13	SP	H 455	12.7	
14		441	12.5	
15		447	13.5	H
16		456	12.6	
17		432	12.8	
18		H 456	13.0	
19		H 456	13.4	H
20		439	12.4	
21	SP	450	12.6	
22	SP	444	12.3	
23		428	13.2	H
24		446	12.1	L
25	SP	448	12.6	
26		434	12.0	
27		H 455	12.5	
28		428	12.2	
29		447	13.5	H
30		443	12.5	
31	SP	444	12.3	
32		435	12.7	
33		441	12.6	
34		L 426	12.5	
35		444	12.8	
36	SP	440	12.8	
37		L 421	12.7	
38		439	12.7	
39	SP	434	12.6	
40	SP	447	13.2	
41		L 422	12.7	
42	SP	441	12.6	
43		434	12.2	
44		442	12.4	
45		434	12.0	L
46		429	12.5	
47		429	12.6	
48		432	12.6	
49	SP	430	12.4	
50	SP	441	12.4	

Pull Pressure

$n = 50$

$\Sigma X^2 = 795849$

$\Sigma X = 6305$

$\frac{\Sigma X^2}{n} = 159.1698$

$\bar{X} = \frac{\Sigma X}{n} = 12.61$

$\bar{X}^2 = 159.0121$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.16} = 0.4$

$\sigma u = .404$

Embedment

$n = 50$

$\Sigma X^2 = 963.3308$

$\Sigma X = 219.42$

$\frac{\Sigma X^2}{n} = 19.266616$

$\bar{X} = \frac{\Sigma X}{n} = 4.3886$

$\bar{X}^2 = 19.2598.099$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{.006806} = .0825, \sigma u = .0833$

$3.126\ \sigma u = .260$

Limit $\bar{X} \pm 3.126\ \sigma u$
4.13 to 4.65

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = 0.032$ $\frac{\sigma u}{\bar{X}} = 0.019$

Code:

H – One of 5 high data
L – One of 5 low data
SP – Spit

APPENDIX F

TEST DATA FOR SHOP ANALYSIS

Operator Certification
Mockup Module Data

TABLE F-I

Dumet (Au)/Ni Ribbon
Weld Schedule and Test Data

Production Operator Certification

Material: **Positive Side** 0.020 Dumet (Au) **Neg. Side** 0.010 x 0.032 Nickel
Electrodes: **Top No.** 2 **Bottom No.** 2 **Machine** HRW-100 **Head** VT60A
Heat 9 1/2 Ws **Pressure** 8 lb

Sample	**Embed-ment**	**Pull**
1	1.66	12.6
2	1.72	14.0
3	1.45	14.6
4	1.86	11.3
5	1.23	12.8
6	1.72	13.6
7	1.70	12.2
8	1.77	13.6
9	1.21	12.7
10	1.41	15.3
11	1.76	13.8
12	1.84	13.8
13	1.87	12.3
14	1.59	15.7
15	1.64	14.8
16	1.68	14.4
17	1.59	12.8
18	1.61	10.0
19	1.70	13.3
20	1.86	13.4
21	1.77	13.5
22	1.72	11.4
23	1.77	13.0
24	1.42	15.5
25	1.92	12.3
26	1.47	13.2
27	1.45	15.0
28	1.86	13.1
29	1.84	13.9
30	1.27	15.6
31	1.87	12.4
32	1.85	13.8
33	1.60	13.2
34	1.39	14.6
35	1.60	13.1
36	1.53	12.4
37	1.35	9.8
38	1.44	12.1
39	1.69	11.8
40	1.87	13.0
41	1.83	12.6
42	1.79	14.3
43	1.59	15.6
44	1.56	13.5
45	1.37	9.5
46	1.76	12.5
47	1.32	12.0
48	1.55	13.5
49	1.38	14.0
50	1.69	12.5

Pull Strength

$n = 50$

$\Sigma X^2 = 8800.63$

$\Sigma X = 659.7$

$$\frac{\Sigma X^2}{n} = 176.0126$$

$$\bar{X} = \frac{\Sigma X}{n} = 13.194$$

$\bar{X}^2 = 174.0816$

$$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$$

$$= \sqrt{1.931} = 139$$

$\sigma u = 1.4$

$$\frac{\sigma u}{\bar{X}} = 0.106$$

Embedment

$n = 50$

$\Sigma X^2 = 134.3171$

$\Sigma X = 81.39$

$$\frac{\Sigma X^2}{n} = 2.68634$$

$$\bar{X} = \frac{\Sigma X}{n} = 1.6278$$

$\bar{X}^2 = 2.64973284$

$$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$$

$$= \sqrt{0.036609} = 0.1913$$

$\sigma u = 0.1932$

$3.126\ \sigma u = 0.604$

Limit ± 3.126 σu
1.02 to 2.23

Coefficient of Variance

$$\frac{\sigma u}{\bar{X}} = 0.106 \qquad \frac{\sigma u}{\bar{X}} = 0.12$$

Code:

H – One of 5 high data
L – One of 5 low data

TABLE F-II

Dumet (Au)/Ni Ribbon
Weld Schedule and Test Data

Production Mockup Modules

Material: Positive Side 0.020 Dumet (Au) Neg. Side 0.010 x 0.032 Ni
Electrodes: Top No. 2 Bottom No. 2 Machine HRW-100 Head VTA 60
Heat 9 1/2 Ws Pressure 8 lb

Sample	Embed-ment	Pull
1	1.68	15.8
2	1.78	16.3
3	1.47	15.7
4	1.59	18.5
5	1.50	17.6
6	1.51	15.8
7	1.85	15.8
8	1.71	14.8
9	1.60	17.3
10	1.57	17.6
11	1.77	14.3
12	1.57	13.4
13	1.78	14.5
14	1.51	10.5
15	1.46	8.5
16	1.47	11.0
17	1.62	9.4
18	1.45	10.6
19	1.91	12.6
20	1.51	15.3
21	1.78	16.5
22	1.84	15.6
23	1.36	13.0
24	1.39	16.8
25	1.41	16.8
26	1.35	14.9
27	1.51	16.9
28	1.50	17.2
29	1.58	17.4
30	1.62	16.4
31	1.56	15.4
32	1.38	14.0
33	1.48	15.0
34	1.24	19.1
35	1.94	17.3
36	1.85	16.9
37	2.08	15.0
38	1.51	17.6
39	1.67	15.7
40	1.38	17.3
41	1.70	16.5
42	1.76	14.6
43	1.77	14.2
44	1.42	16.4
45	1.41	17.2
46	1.27	14.1
47	1.72	17.5
48	1.61	10.5
49	1.31	16.3
50	1.59	18.5

Pull Strength

$n = 50$

$\Sigma X^2 = 12020.35$

$\Sigma X = 765.9$

$\frac{\Sigma X^2}{n} = 240.4070$

$\bar{X} = \frac{\Sigma X}{n} = 15.318$

$\bar{X}^2 = 234.6411$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{5.7659} = 2.4$

$\sigma u = 2.42$

Embedment

$n = 50$

$\Sigma X^2 = 127.4570$

$\Sigma X = 79.30$

$\frac{\Sigma X^2}{n} = 2.549140$

$\bar{X} = \frac{\Sigma X}{n} = 1.5860$

$\bar{X}^2 = 2.515396$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{337.44} = 0.1837$

$\sigma u = 0.1855$

	Min	Max	$\bar{X}$	σ
Statistical limits established from operator certification	1.02	2.23	1.63	0.19
Actual module weld limits	1.24	2.08	1.59	0.19

Coef of Variance = 0.16 Coef of Variance = 0.12

TABLE F-III

Dumet (Au)/Alloy 180 Wire
Weld Schedule and Test Data

Production Operator Certification

Material: **Positive Side** 0.20 Dumet (Au) **Neg. Side** 0.20 Alloy 180
Electrodes: **Top No.** 2 **Bottom No.** 2 **Machine** HRW-100 **Head** VTA-60
Heat 5.75 Ws **Pressure** 6 lb Goddard SN 226111

Sample	Embedment	Pull
1	3.13	14.7
2	2.53	13.1
3	2.59	7.6
4	3.07	15.0
5	2.69	10.2
6	2.90	15.3
7	2.47	9.6
8	3.29	10.6
9	2.54	10.7
10	2.45	13.0
11	2.66	14.6
12	2.90	15.7
13	2.70	14.3
14	2.76	14.0
15	2.72	14.8
16	3.03	14.9
17	2.61	14.0
18	2.95	13.8
19	2.78	8.4
20	2.73	14.0
21	3.02	15.0
22	2.63	13.7
23	2.87	13.8
24	2.55	9.8
25	2.47	13.1
26	2.50	14.6
27	2.50	13.3
28	2.58	14.5
29	2.68	10.2
30	2.89	9.5
31	2.56	14.5
32	3.22	15.0
33	2.81	8.0
34	2.57	15.1
35	2.95	14.5
36	2.59	14.0
37	2.91	13.8
38	2.78	12.4
39	2.67	15.0
40	2.57	8.8
41	2.51	14.7
42	2.88	14.5
43	2.80	14.9
44	2.77	15.2
45	2.76	10.0
46	2.73	14.3
47	2.65	10.3
48	2.61	10.3
49	2.54	13.0
50	2.50	14.7

Pull Strength

$n = 50$

$\Sigma X^2 = 8674.45$

$\Sigma X = 648.7$

$\frac{\Sigma X^2}{n} = 173.4890$

$\bar{X} = \frac{\Sigma X}{n} = 12.974$

$\bar{X}^2 = 168.3247$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{5.1643} = 2.27$

$\sigma u = 2.3$

Embedment

$n = 50$

$\Sigma X^2 = 375.0709$

$\Sigma X = 136.57$

$\frac{\Sigma X^2}{n} = 7.501418$

$\bar{X} = \frac{\Sigma X}{n} = 2.7314$

$\bar{X}^2 = 7.460546$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.040872} = 0.2022$

$\sigma u = 0.2042$, $3.126\ \sigma u = 0.6383$

Limits $\bar{X} \pm 3.126\ \sigma u$
2.1 to 3.4

Coefficient of Variance

Pull Strength: $\frac{\sigma u}{\bar{X}} = 0.18$

Embedment: $\frac{\sigma u}{\bar{X}} = 0.075$

TABLE F-IV

Dumet (Au)/Alloy 180 Wire
Weld Schedule and Test Data

Production Mockup Modules

Material: **Positive Side** 0.020 Dumet (Au) **Neg. Side** 0.020 Alloy 180
Electrodes: **Top No.** 2 **Bottom No.** 2 **Machine** **Head**
Heat 5.75 Ws **Pressure** 6 lb

Sample	**Embedment**	**Pull**
1	3.09	10.4
2	3.17	14.0
3	3.18	14.2
4	2.62	8.9
5	2.87	14.7
6	3.05	14.6
7	2.83	12.9
8	3.29	13.9
9	2.83	13.1
10	3.62	14.6
11	2.71	14.1
12	3.82	14.4
13	3.02	14.0
14	3.18	14.0
15	3.24	14.8
16	3.21	14.4
17	1.50	2.3
18	2.88	14.6
19	2.68	14.2
20	2.96	13.7
21	2.44	15.4
22	3.18	14.4
23	2.75	14.7
24	3.15	14.8
25	2.91	14.5
26	3.13	14.1
27	3.09	14.2
28	2.80	15.0
29	3.16	14.7
30	3.24	14.5
31	3.35	13.8
32	2.82	14.0
33	3.39	15.3
34	3139	14.7
35	3.41	14.5
36	2.81	14.6
37	2.27	14.4
38	2.44	12.0
39	2.39	15.3
40	2.99	14.8
41	3.31	14.2
42	3.30	14.7
43	4.09	13.0
44	3.10	14.5
45	3.51	15.1
46	3.05	15.0
47	2.92	14.1
48	2.71	14.5
49	3.70	14.8
50	3.02	14.0
51	3.13	14.4

Pull Strength	Embedment
$n = 50$	$n = 50$
$\Sigma X^2 = 10073.37$	$\Sigma X^2 = 475.3983$
$\Sigma X = 707.5$	$\Sigma X = 153.15$
$\frac{\Sigma X^2}{n} = 201.4674$	$\frac{\Sigma X^2}{n} = 9.507966$
$\bar{X} = \frac{\Sigma X}{n} = 14.150$	$\bar{X} = \frac{\Sigma X}{n} = 3.0630$
$\bar{X}^2 = 200.225$	$\bar{X}^2 = 9.381969$
$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$	$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$
$= \sqrt{1.2449} = 1.12$	$= \sqrt{0.125997} = 0.355$
$\sigma u = 1.13$	$\sigma u = 0.36$, $3.126\ \sigma u = 1.12$
$\frac{\sigma u}{\bar{X}} = 0.08$	
Module No. 1 to 6	

	Min	Max	$\bar{X}$	σu
Statistical limits established from operator certification	2.1	3.4	2.73	0.2
Actual module weld limits	2.27	4.09	3.06	0.36

Coef of Variance = 0.8

Coef of Variance = 0.12

TABLE F-V

Kovar (Au)/Ni Ribbon
Weld Schedule and Test Data

Production Operator Certification

Material: Positive Side 017 Kovar (Au) Neg. Side 0.010 x 0.032 Ni Ribbon
Electrodes: Top No. 2 Bottom No. 2 Machine HRW-100 Head VTA 60
Heat 5 1/2 Ws Pressure 6 lb

Sample	Embedment	Pull
1	1.82	13.6
2	1.60	14.8
3	1.88	12.1
4	1.56	15.4
5	1.63	16.7
6	1.68	16.4
7	1.73	15.3
8	1.63	14.8
9	1.63	12.6
10	1.48	14.1
11	1.49	13.1
12	1.67	14.3
13	1.83	14.6
14	1.67	14.8
15	1.63	13.5
16	1.58	13.8
17	1.54	12.0
18	1.82	14.1
19	1.68	12.8
20	1.66	12.9
21	1.60	14.8
22	1.66	14.0
23	2.15	15.1
24	1.88	14.8
25	1.38	11.0
26	1.66	12.5
27	1.52	13.6
28	1.30	12.5
29	1.34	13.1
30	1.85	14.0
31	1.70	14.1
32	1.63	12.0
33	1.83	14.3
34	1.45	12.1
35	1.89	14.8
36	1.68	14.7
37	1.54	15.3
38	1.87	13.0
39	1.59	15.5
40	1.68	15.3
41	1.59	16.2
42	2.15	16.7
43	2.04	15.8
44	2.03	14.0
45	1.55	14.5
46	1.60	15.3
47	1.58	14.8
48	1.59	14.3
49	1.53	13.8
50	1.46	14.8

Pull Strength

$n = 50$

$\Sigma X^2 = 10092.92$

$\Sigma X = 707.5$

$\frac{\Sigma X^2}{n} = 201.8584$

$\bar{X} = \frac{\Sigma X}{n} = 14.150$

$\bar{X}^2 = 200.2225$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{1.6359} = 1.28$

$\sigma u = 1.29$

Embedment

$n = 50$

$\Sigma X^2 = 141.8483$

$\Sigma X = 83.73$

$\frac{\Sigma X^2}{n} = 2.836966$

$\bar{X} = \frac{\Sigma X}{n} = 1.6746$

$\bar{X}^2 = 2.804285$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{326.11} = 0.1806$

$\sigma u = 0.1824$, $3.126\ \sigma u = 0.570$

Limits $\bar{X} \pm 3.126\sigma$
1.10 to 2.25

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = 0.091$ $\frac{\sigma u}{\bar{X}} = 0.11$

TABLE F-VI

Kovar (Au)/Ni Ribbon
Weld Schedule and Test Data

Production Mockup Modules

Material: **Positive Side** 017 Kovar **Neg. Side** 0.010 x 0.32 Ni Ribbon
Electrodes: **Top No.** 2 **Bottom No.** 2 **Machine** HRW-100 **Head** VTA 60
Heat 5 1/2 Ws **Pressure** 6

Sample	Embedment	Pull
1	1.78	14.6
2	1.39	12.6
3	1.54	14.1
4	1.71	15.0
5	1.57	13.8
6	1.64	13.8
7	1.91	12.6
8	1.60	13.1
9	1.67	14.6
10	1.65	12.6
11	1.80	14.0
12	1.75	13.7
13	2.00	14.3
14	1.67	15.4
15	1.80	15.0
16	1.79	14.7
17	1.80	16.5
18	1.65	13.0
19	1.78	15.6
20	1.78	15.0
21	1.70	16.0
22	2.07	15.3
23	1.59	15.0
24	1.93	15.1
25	1.71	16.3
26	1.71	16.3
27	1.52	11.8
28	1.63	16.0
29	1.45	13.0
30	1.61	15.4
31	1.48	15.2
32	1.62	10.3
33	1.73	12.3
34	1.80	10.2
35	1.77	15.0
36	2.17	12.5
37	1.47	11.6
38	1.79	13.1
39	1.73	12.8
40	1.74	16.8
41	1.52	16.5
42	1.52	14.6
43	1.30	15.8
44	1.74	15.5
45	1.52	16.1
46	1.60	16.4
47	2.04	15.6
48	1.37	13.5
49	1.65	15.8
50	1.64	15.4

Pull Strength

$n = 50$

$\Sigma X^2 = 10501.66$

$\Sigma X = 720.2$

$\frac{\Sigma X^2}{n} = 210.0332$

$\bar{X} = \frac{\Sigma X}{n} = 14.404$

$\bar{X}^2 = 207.4752$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{2.558} = 1.6$

$\sigma u = 1.61, \frac{\sigma u}{\bar{X}} = 0.11$

Embedment

$n = 50$

$\Sigma X^2 = 143.9774$

$\Sigma X = 84.40$

$\frac{\Sigma X^2}{n} = 2.879548$

$\bar{X} = \frac{\Sigma X}{n} = 1.6880$

$\bar{X}^2 = 2.849344$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.30204} = 0.1738$

$\sigma u = 0.1755$

	Min	Max	$\bar{X}$	σu
Statistical limits established from operator certification	1.1	2.25	1.67	0.18
Actual module weld limits	1.3	2.17	1.69	0.18

Coef of Variance = 0.11 Coef of Variance = 0.10

TABLE F-VII

Kovar (Au)/Alloy 180 Wire
Weld Schedule and Test Data

Production Operator Certification

Material: Positive Side 0.017 Kovar — Neg. Side Alloy 180 0.020
Electrodes: Top No. 2 — Bottom No. 2 — Machine HRW-100 — Head VTA 60
Heat 3.75 Ws — Pressure 4 lb

Sample	Embedment	Pull
1	3.28	11.0
2	4.01	13.3
3	3.35	11.3
4	2.92	10.8
5	3.30	12.3
6	3.65	12.8
7	3.66	12.5
8	3.17	12.2
9	3.05	11.4
10	3.61	12.2
11	3.15	11.3
12	3.65	11.8
13	3.54	11.8
14	3.82	12.3
15	3.66	11.3
16	3.81	11.6
17	3.65	12.2
18	4.62	11.6
19	3.62	11.8
20	3.69	11.5
21	3.66	12.1
22	3.33	11.5
23	3.27	12.1
24	3.31	11.9
25	3.13	11.1
26	3.27	11.1
27	3.34	11.8
28	3.10	11.0
29	3.26	11.8
30	3.69	12.5
31	3.81	12.0
32	3.34	11.8
33	3.17	12.1
34	3.35	11.4
35	3.44	12.7
36	3.26	11.3
37	3.39	11.5
38	3.43	11.7
39	3.29	11.9
40	3.44	12.5
41	3.15	11.7
42	3.48	11.0
43	3.22	11.8
44	3.44	11.3
45	3.24	11.3
46	3.11	11.5
47	3.28	11.7
48	3.48	11.3
49	3.49	12.3
50	3.54	12.2

Pull Strength

$n = 50$

$\Sigma X^2 = 6949.73$

$\Sigma X = 588.9$

$\frac{\Sigma X^2}{n} = 138.5946$

$\bar{X} = \frac{\Sigma X}{n} = 11.778$

$\bar{X}^2 = 138.7213$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.8733} = 0.93$

$\sigma u = 0.94, \frac{\sigma u}{\bar{X}} = 0.08$

Embedment

$n = 50$

$\Sigma X^2 = 595.1838$

$\Sigma X = 171.92$

$\frac{\Sigma X^2}{n} = 11.90367600$

$\bar{X} = \frac{\Sigma X}{n} = 3.4384$

$\bar{X}^2 = 11.82259456$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.08108144} = 0.28475$

$\sigma u = 0.29, \ 3.126\sigma = 89.9$

Limits $\bar{X} \pm 3126\sigma$
2.54 to 4.34

Coefficient of Variance

Pull Strength: $\frac{\sigma u}{\bar{X}} = 0.08$

Embedment: $\frac{\sigma u}{\bar{X}} = 0.084$

TABLE F-VIII

Kovar (Au) to Alloy 180 Wire
Weld Schedule and Test Data

Production Mockup Modules

Material: Positive Side 0.017 Kovar Neg. Side 0.020 Alloy 180
Electrodes: Top No. 2 Bottom No. 2 Machine HRW-100 Head VTA 60
Heat 3.75 Ws Pressure 4 lb

Sample	Embedment	Pull
1	3.49	11.9
2	3.45	13.4
3	3.08	11.9
4	4.01	12.3
5	4.25	11.7
6	3.87	13.3
7	3.50	11.6
8	3.56	11.4
9	3.47	12.4
10	3.77	11.1
11	4.02	11.9
12	3.41	11.8
13	3.54	12.1
14	3.51	12.9
15	3.53	12.1
16	3.30	11.5
17	4.72	13.3
18	4.05	13.8
19	3.43	13.3
20	3.58	11.4
21	3.82	13.0
22	3.56	12.4
23	3.25	13.1
24	3.72	12.4
25	2.98	10.9
26	3.51	12.3
27	3.52	12.0
28	3.78	12.4
29	3.62	11.9
30	3.50	12.0
31	3.91	13.1
32	3.28	11.0
33	3.86	13.2
34	3.74	13.2
35	3.25	12.4
36	3.49	11.9
37	4.01	12.8
38	3.59	13.3
39	3.00	11.3
40	3.71	12.8
41	3.72	12.6
42	3.56	13.3
43	4.07	12.9
44	3.70	13.1
45	3.43	12.3
46	3.43	12.3
47	3.79	12.8
48	3.63	12.6
49	3.54	12.6
50	3.62	12.4

Pull Strength

$n = 50$

$\Sigma X^2 = 7697.54$

$\Sigma X = 619.4$

$\frac{\Sigma X^2}{n} = 153.9508$

$\bar{X} = \frac{\Sigma X}{n} = 12.388$

$\bar{X}^2 = 153.4625$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.4883} = 0.7$

$\sigma u = 0.707$

Embedment

$n = 50$

$\Sigma X^2 = 660.9021$

$\Sigma X = 18.113$

$\frac{\Sigma X^2}{n} = 13.218042$

$\bar{X} = \frac{\Sigma X}{n} = 3.6226$

$\bar{X}^2 = 13.123230$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.094812} = 0.308$

$\sigma u = 0.311,\ 3.126\ \sigma u = 0.97$

	Min	Max	$\bar{X}$	σu
Statistical limits established from operator certification	2.54	4.34	3.44	0.29
Actual module weld limits	2.98	4.72	3.62	0.31

Coef of Variance = 0.06 Coef of Variance = 0.086

APPENDIX G

MANUAL VERSUS PNEUMATIC WELD HEAD COMPARATIVE DATA OBTAINED VIA PRODUCTION OPERATOR

TABLE G-I

Dumet (Au)/Ni Ribbon
Weld Schedule and Test Data

Standard Weld Head

Material: Positive Side 0.020 Dumet (Au) Neg. Side 0.010 x 0.032 Ni
Electrodes: Top No. 2 Bottom No. 2 Machine HRW 100 MG Head VTA 60
Heat 10 Pressure 8 lb

Sample	Embed-ment	Pull
1	2.24	14.0
2	2.05	14.1
3	1.98	11.5
4	2.09	11.8
5	2.19	11.4
6	2.12	11.6
7	1.99	11.7
8	1.96	11.8
9	1.77	13.4
10	2.17	13.8
11	2.30	13.3
12	1.89	13.4
13	1.84	12.4
14	2.09	11.8
15	2.05	12.9
16	2.78	12.0
17	2.20	12.8
18	1.76	12.1
19	2.58	12.6
20	2.13	11.2
21	2.50	11.5
22	2.27	11.6
23	2.32	11.9
24	2.44	15.0
25	2.54	14.1
26	2.22	12.7
27	2.66	12.2
28	2.58	13.9
29	2.59	12.9
30	2.32	14.0
31	2.56	12.1
32	2.20	13.4
33	2.38	12.3
34	2.60	13.5
35	2.32	11.4
36	2.09	11.3
37	1.99	12.7
38	2.18	12.9
39	2.03	12.6
40	1.92	11.8
41	2.76	11.8
42	2.64	12.6
43	2.59	13.5
44	2.58	12.8
45	2.38	12.4
46	2.12	12.1
47	2.17	13.9
48	1.86	12.6
49	1.99	11.4
50	1.93	13.7

Pull Strength

$n = 50$

$\Sigma X^2 = 7{,}843.980$

$\Sigma X = 620.200$

$\frac{\Sigma X^2}{n} = 156.8796$

$\bar{X} = \frac{\Sigma X}{n} = 12.40$

$\bar{X}^2 = 153.76$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{3.1196} = 1.766$

$\sigma u = 1.784, \frac{\sigma}{\bar{X}} = \frac{1.766}{12.40} = 0.142$

Limits $\bar{X} \pm 3\sigma$
$= 12.2580$ to 12.542

Embedment

$n = 50$

$\Sigma X^2 = 248.3639$

$\Sigma X = 110.41$

$\frac{\Sigma X^2}{n} = 4.967$

$\bar{X} = \frac{\Sigma X}{n} = 2.208$

$\bar{X}^2 = 4.875$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.092} = 0.3033$

$\sigma u = 0.3063, 3.126\ \sigma u = 0.957$

Limits $\bar{X} \pm 3.126\sigma$
$= 1.2510$ to 3.165

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = \frac{1.784}{12.4} = 0.144$

$\frac{\sigma u}{\bar{X}} = \frac{0.306}{2.21} = 0.138$

TABLE G-II

Dumet (Au)/Ni Ribbon
Weld Schedule and Test Data

Pneumatic Weld Head

Material: Positive Side 0.020 Dumet (Au) Neg. Side 0.010 x 0.032 Nickel Ribbon
Electrodes: Top No. 2 Bottom No. 2 Machine HRW 100 MG Head VTA 60
Heat 10 Ws Pressure 8 lb

Sample	Embed-ment	Pull
1	3.60	13.4
2	3.56	15.0
3	3.50	13.1
4	3.56	12.7
5	3.69	13.5
6	3.69	14.5
7	3.46	14.0
8	3.57	12.9
9	3.58	13.1
10	3.22	16.4
11	3.72	12.3
12	3.45	12.4
13	3.65	14.4
14	3.49S	13.5
15	3.44	15.1
16	3.35	17.5
17	3.62	14.7
18	3.53	15.0
19	3.42	16.2
20	3.62	14.8
21	3.52	14.6
22	3.54	14.8
23	3.45	14.3
24	3.55S	12.3
25	3.41	13.7
26	3.44	13.2
27	3.52	14.9
28	3.41	13.8
29	3.34	13.7
30	3.53S	14.0
31	3.58	12.2
32	3.48S	13.8
33	3.39	16.0
34	3.48	13.2
35	3.62	13.0
36	3.51	12.4
37	3.59	15.1
38	3.43S	15.0
39	3.37	15.8
40	3.51S	14.5
41	3.64	14.9
42	3.57	15.2
43	3.40	13.6
44	3.34S	15.3
45	3.46S	14.6
46	3.37S	15.7
47	3.48S	14.6
48	3.48S	15.0
49	3.43	14.3
50	3.46	14.6

Pull Strength

$n = 50$

$\Sigma X^2 = 10223.22000$

$\Sigma X = 712.600000$

$\frac{\Sigma X^2}{n} = 204.46440$

$\bar{X} = \frac{\Sigma X}{n} = 14.25200$

$\bar{X}^2 = 203.11950$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{1.3449} - 1.1597$

$\sigma u = 1.17$

Limits $\bar{X} \pm 3\sigma$

Embedment

$n = 50$

$\Sigma X^2 = 612.55050$

$\Sigma X = 174.93000$

$\frac{\Sigma X^2}{n} = 12.2510$

$\bar{X} = \frac{\Sigma X}{n} = 3.4986$

$\bar{X}^2 = 12.24020$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.01080} = 0.10392 \times 1.01$

$\sigma u = 0.10496,\ 3.126\sigma = 0.3376$

Limits $\bar{X} \pm 3.126\ \sigma u$
$= 3.1610$ to 3.8362

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = \frac{1.17}{14.3} = 0.08$

$\frac{\sigma u}{X} = \frac{0.105}{3.5} = 0.03$

TABLE G-III

Dumet (Au)/Alloy 180 Wire
Weld Schedule and Test Data

Standard Weld Head

Material: **Positive Side** 0.020 Dumet, (Au) **Neg. Side** 0.020 180 Alloy 180
Electrodes: **Top No.** 2 **Bottom No.** 2 **Machine** HRW-100 MG **Head** VTA 60
Heat 5 3/4 Ws **Pressure** 6 lb

Sample	Embed-ment	Pull
1	4.03	15.2
2	3.87	15.5
3	4.43	14.6
4	4.17	14.5
5	4.18	15.2
6	4.16	15.1
7	3.96	15.4
8	3.88	15.3
9	3.22	14.2
10	4.15	15.1
11	4.09	15.2
12	4.37	14.4
13	3.67	15.2
14	4.01	15.0
15	3.51	15.5
16	3.78	15.0
17	4.34	14.6
18	3.96	15.0
19	4.01	15.4
20	3.81	15.2
21	4.19	15.0
22	3.73	15.5
23	4.10	14.8
24	3.78	15.2
25	3.86	14.9
26	3.62	14.7
27	3.70	14.7
28	3.75	15.3
29	4.21	14.8
30	3.84	15.5
31	3.71	15.3
32	3.88	14.7
33	3.85	14.9
34	3.73	14.8
35	3.64	15.1
36	4.22	14.4
37	3.84	15.0
38	3.63	15.6
39	4.01	14.4
40	4.07	14.6
41	3.74	14.9
42	3.93	14.5
43	3.81	14.6
44	3.71	15.0
45	3.85	14.9
46	3.72	15.2
47	4.30	14.0
48	4.23	14.4
49	3.85	14.5
50	4.37	14.7

Pull Strength

$n = 50$

$\Sigma X^2 = 11{,}149.3400$

$\Sigma X = 746.400$

$\frac{\Sigma X^2}{n} = 222.98680$

$\bar{X} = \frac{\Sigma X}{n} = 14.92800$

$\bar{X}^2 = 222.84518$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.141620} = 0.37632$

$\sigma u = 0.380$

Embedment

$n = 50$

$\Sigma X^2 = 756.36130$

$\Sigma X = 192.470$

$\frac{\Sigma X^2}{n} = 15.12723$

$\bar{X} = \frac{\Sigma X}{n} = 3.849400$

$\bar{X}^2 = 14.81788$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.30935} = 0.556$

$\sigma u = 0.562$, $3.126\ \sigma u = 1.76$

Limits $\bar{X} \pm 3.126\ \sigma u$
$= 2.09$ to 5.6

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = \frac{0.38}{14.93} = 0.025$

$\frac{\sigma u}{\bar{X}} = \frac{0.562}{3.85} = 0.146$

TABLE G-IV

Dumet (Au)/Alloy 180 Wire
Weld Schedule and Test Data

Pneumatic Weld Head

Material: Positive Side 0.020 Dumet (Au) Neg. Side 0.020 Alloy 180
Electrodes: Top No. 2 Bottom No. 2 Machine HRW-100 MG Head VTA 60
Heat 5.75 Ws Pressure 6 lb

Sample	Embedment	Pull
1	3.83	14.3
2	3.98	14.6
3	3.86	14.2
4	3.70	15.0
5	3.67	15.0
6	3.98	14.5
7	3.87	15.3
8	3.54	15.8
9	3.64	15.0
10	3.68	15.7
11	3.86	15.4
12	3.75	15.2
13	3.81	15.0
14	3.63	15.1
15	3.94	13.0
16	3.54	15.2
17	3.98	15.6
18	3.98	15.3
19	3.62	15.5
20	4.11	14.6
21	3.79	15.3
22	4.01	15.3
23	3.96	15.1
24	3.86	14.3
25	3.76	15.0
26	3.72	15.9
27	3.74	15.4
28	3.82	15.8
29	3.87	14.9
30	3.86	15.0
31	4.02	14.3
32	3.84	14.8
33	3.70	15.2
34	3.87	15.1
35	3.93	15.6
36	3.94	15.3
37	4.12	14.5
38	3.66	15.5
39	3.75	14.7
40	3.91	14.6
41	3.61	15.3
42	3.62	15.2
43	3.66	15.5
44	3.52	15.9
45	3.92	14.3
46	3.82	15.7
47	3.82	15.0
48	3.98	15.2
49	3.80	14.6
50	3.88	14.3

Pull Strength

$n = 50$

$\Sigma X^2 = 11291.2100$

$\Sigma X = 750.900$

$\frac{\Sigma X^2}{n} = 225.82420$

$\bar{X} = \frac{\Sigma X}{n} = 15.01800$

$\bar{X}^2 = 225.54032$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.283880} = 0.5328$

$\sigma u = 0.538, \frac{\sigma}{\bar{X}} = \frac{0.5328}{15.018}$

$= 0.03548$

Embedment

$n = 50$

$\Sigma X^2 = 721.52360$

$\Sigma X = 189.720$

$\frac{\Sigma X^2}{n} = 14.43047$

$\bar{X} = \frac{\Sigma X}{n} = 3.79440$

$\bar{X}^2 = 14.39747$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.03300} = 0.1816$

$\sigma u = 0.183, \ 3.126\sigma = 0.573$

Limits $\bar{X} \pm 3.126\sigma u$
$= 3.22$ to 4.37

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = \frac{0.538}{15.02} = 0.036$

$\frac{\sigma u}{\bar{X}} = \frac{0.183}{3.8} = 0.0482$

TABLE G-V

Kovar (Au)/Ni Ribbon
Weld Schedule and Test Data

Standard Weld Head

Material: Positive Side 0.017 Kovar (Au) Neg. Side 0.010 x 0.032 Nickel
Electrodes: Top No. 2 Bottom No. 2 Machine HRW-100 MG Head VTA 60
Heat 4 3/4 Ws Pressure 6 lb

Sample	Embedment	Pull
1	1.14	10.8
2	1.08	9.0
3	1.22	6.5
4	1.13	13.0
5	1.17	11.8
6	1.07	12.8
7	1.11	11.3
8	1.23	11.4
9	1.10	11.5
10	1.20	13.0
11	1.17	10.5
12	1.15	10.5
13	1.15	12.7
14	1.16	12.0
15	1.11	10.0
16	1.14	8.7
17	1.16	12.1
18	1.00	9.1
19	1.12	10.0
20	1.15	12.1
21	1.05	13.0
22	1.12	11.3
23	1.15	13.2
24	1.18	12.0
25	1.17	10.8
26	1.19	10.6
27	1.23	10.7
28	1.17	13.0
29	1.34	13.9
30	1.14	10.4
31	1.21	10.3
32	1.23	10.0
33	1.21	12.4
34	1.14	9.3
35	1.09	13.7
36	1.18	9.0
37	1.21	10.7
38	1.33	9.2
39	1.11	10.4
40	1.29	10.7
41	1.27	7.6
42	1.28	12.9
43	1.16	12.8
44	1.19	15.0
45	1.31	9.5
46	1.18	9.8
47	1.24	9.8
48	1.18	10.8
49	1.04	13.2
50	1.07	11.5

Pull Strength

$n = 50$

$\Sigma X^2 = 5332.050000$

$\Sigma X = 556.30000$

$\frac{\Sigma X^2}{n} = 126.64100$

$\bar{X} = \frac{\Sigma X}{n} = 11.12600$

$\bar{X}^2 = 123.78788$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{2.85312} = 1.6891$

$\sigma u = 1.70$

Embedment

$n = 50$

$\Sigma X^2 = 68.5160$

$\Sigma X = 58.42$

$\frac{\Sigma X^2}{n} = 1.370320$

$\bar{X} = \frac{\Sigma X}{n} = 1.1684$

$\bar{X}^2 = 1.36515856$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.005161} = 0.0718$

$\sigma u = 0.0725$, $3.126\ \sigma u = 0.227$

Limits $\bar{X} \pm 3.126\ \sigma u$
$= 0.94$ to 1.4

Coefficient of Variance

Pull Strength: $\frac{\sigma u}{\bar{X}} = 0.153$

Embedment: $\frac{\sigma u}{\bar{X}} = 0.062$

TABLE G-VI

Kovar (Au)/Ni Ribbon
Weld Schedule and Test Data

Pneumatic Weld Head

Material: Positive Side 0.017 Kovar (Au) Neg. Side 0.010 x 0.032 Nickel Ribbon
Electrodes: Top No. 2 Bottom No. 2 Machine HRW-100 MG Head VTA 60
Heat Pressure

Sample	Embed-ment	Pull
1	1.71	16.4
2	1.59	14.2
3	1.54	14.1
4	1.55	15.5
5	1.61	14.0
6	1.66	12.7
7	1.59	13.8
8	1.62	13.8
9	1.53	14.5
10	1.61	16.3
11	1.61	15.0
12	1.57	12.2
13	1.65	14.2
14	1.54	15.3
15	1.63	15.5
16	1.60	16.1
17	1.70	14.8
18	1.61	16.5
19	1.61	16.4
20	1.84	15.0
21	1.67	14.4
22	1.61	14.0
23	1.60	14.8
24	1.71	15.4
25	1.68	15.4
26	1.63	14.7
27	1.60	16.7
28	1.53	16.3
29	1.59	13.6
30	1.65	16.4
31	1.57	16.0
32	1.64	15.9
33	1.57	13.6
34	1.67	15.3
35	1.63	14.2
36	1.71	15.6
37	1.58	15.2
38	1.64	13.5
39	1.63	14.1
40	1.73	16.8
41	1.86	15.5
42	1.66	16.7
43	1.73	15.3
44	1.62	12.6
45	1.60	16.0
46	1.73	14.5
47	1.54	16.8
48	1.54	14.7
49	1.56	16.3
50	1.60	16.8

Pull Strength

$n = 50$

$\Sigma X^2 = 11424.106$

$\Sigma X = 753.5100$

$\frac{\Sigma X^2}{n} = 230.48212$

$\bar{X} = \frac{\Sigma X}{n} = 15.0702$

$\bar{X}^2 = 227.11093$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.33712} = 0.5806$

$\sigma u = 0.586$

Embedment

$n = 50$

$\Sigma X^2 = 132.9305$

$\Sigma X = 81.4500$

$\frac{\Sigma X^2}{n} = 2.658610$

$\bar{X} = \frac{\Sigma X}{n} = 1.6290$

$\bar{X}^2 = 2.653641$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.004969} = 0.07049$, $\sigma u = 0.07120$

$3.126\ \sigma u = 0.2226$

Limits $\bar{X} \pm 3\sigma$
$= 2.436010$ to 2.881210

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = \frac{0.59}{15.1} = 0.0391$

$\frac{\sigma u}{\bar{X}} = \frac{0.07}{1.6} = 0.0438$

TABLE G-VII

Kovar (Au)/Alloy 180 Wire
Weld Schedule and Test Data

Standard Weld Head

Material: Positive Side 0.017 Kovar (Au) **Neg. Side** 0.020 Alloy 180
Electrodes: Top No. 2 **Bottom No.** 2 **Machine** HRW-100 MG **Head** VTA 60
Heat 3.75 Ws **Pressure** 4 lb

Sample	Embed-ment	Pull
1	2.83	11.5
2	2.91	11.5
3	2.78	10.9
4	2.69	10.7
5	2.65	12.0
6	2.75	12.2
7	2.72	11.1
8	2.93	11.4
9	3.12	12.0
10	2.92	11.6
11	3.09	11.0
12	2.83	11.1
13	2.83	10.8
14	2.76	11.5
15	2.86	11.3
16	2.76	11.5
17	2.89	10.8
18	2.63	11.2
19	2.71	11.6
20	2.69	12.2
21	2.79	10.3
22	2.74	11.0
23	2.78	11.7
24	3.00	11.5
25	2.87	11.4
26	2.74	11.6
27	2.49	10.8
28	2.69	11.1
29	2.86	11.7
30	2.77	11.5
31	2.62	11.2
32	2.95	11.2
33	2.93	11.5
34	2.59	11.2
35	2.74	11.4
36	2.71	11.5
37	2.69	11.5
38	2.75	11.4
39	2.66	11.7
40	2.68	11.6
41	2.80	11.5
42	2.71	10.8
43	2.81	11.0
44	2.68	11.0
45	2.98	10.6
46	2.74	11.2
47	2.87	10.6
48	2.70	11.1
49	2.74	10.8
50	2.87	10.6

Pull Strength

$n = 50$

$\Sigma X^2 = 6368.3300$

$\Sigma X = 563.900$

$\frac{\Sigma X^2}{n} = 127.3666$

$\bar{X} = \frac{\Sigma X}{n} = 11.278$

$\bar{X}^2 = 127.1933$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.1733} = 0.4163$

$\frac{\sigma}{\bar{X}} = \frac{0.4163}{11.278}$

$\frac{\sigma}{\bar{X}} = 0.037$

Embedmet

$n = 50$

$\Sigma X^2 = 389.2157$

$\Sigma X = 139.370$

$\frac{\Sigma X^2}{n} = 7.7843$

$\bar{X} = \frac{\Sigma X}{n} = 2.7874$

$\bar{X}^2 = 7.7696$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.014700} = 0.12105 \times 1.01$

$\sigma u = 0.1223$, $3.126\ \sigma u = 0.3823$

Limits $\bar{X} \pm 3.126\ \sigma u$
2.41 to 3.17

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = \frac{0.416}{11.28} = 0.037$ $\frac{\sigma u}{\bar{X}} = \frac{0.1223}{2.787} = 0.0442$

TABLE G-VIII

Kovar (Au)/Alloy 180 Wire
Weld Schedule and Test Data

Pneumatic Weld Head

Material: Positive Side 0.017 Kovar (Au) | Neg. Side 0.020 Alloy 180
Electrodes: Top No. 2 | Bottom No. 2 | Machine HRW-100 MG | Head VTA-60
Heat 3.75 Ws | **Pressure** 4 lb

Sample	Embedment	Pull
1	3.52	12.5
2	3.61	11.4
3	3.49	12.0
4	3.59	12.0
5	3.64	11.5
6	3.50	11.6
7	3.56	11.7
8	3.41	11.6
9	3.60	11.3
10	3.43	11.5
11	3.52	12.0
12	3.52	11.7
13	3.55	12.1
14	3.51	12.6
15	3.64	11.7
16	3.52	12.1
17	3.63	11.6
18	3.53	11.8
19	3.57	11.8
20	3.60	11.9
21	3.73	11.5
22	3.48	11.5
23	3.66F	11.6
24	3.52	11.9
25	3.70	11.5
26	3.54	11.3
27	3.64	11.6
28	3.55	11.7
29	3.57	11.6
30	3.60	11.6
31	3.58	12.2
32	3.77F	12.5
33	3.55	11.5
34	3.72	11.9
35	3.49	11.5
36	3.48	11.6
37	3.68	11.4
38	3.57	11.6
39	3.64	11.5
40	3.46	12.9
41	3.65	11.3
42	3.46	12.4
43	3.39	12.6
44	3.52	12.0
45	3.48	11.7
46	3.41	11.9
47	3.43	11.5
48	3.47	12.4
49	3.36	11.7
50	3.47	11.2

Pull Strength

$n = 50$

$\Sigma X^2 = 6957.5900$

$\Sigma X = 589.500$

$\frac{\Sigma X^2}{n} = 139.15180$

$\bar{X} = \frac{\Sigma X}{n} = 11.7900$

$\bar{X}^2 = 139.0041$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.1477} = 0.38432 \times 1.01$

$\sigma u = 0.388$

$\frac{\sigma}{\bar{X}} = \frac{0.38432}{11.7900} = 0.03597$

Limits $\bar{X} \pm 3\sigma$

Embedment

$n = 50$

$\Sigma X^2 = 630.68380$

$\Sigma X = 177.520$

$\frac{\Sigma X^2}{n} = 12.6136$

$\bar{X} = \frac{\Sigma X}{n} = 3.5504$

$\bar{X}^2 = 12.605340$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.008260} = 0.09088 \times 1.01$

$\sigma u = 0.091789$

$3.126\ \sigma u = 0.2869$

Limits $\bar{X} \pm 3.126\sigma u$
$= 3.2635$ to 3.8373

Coefficient of Variance

$\frac{\sigma u}{\bar{X}} = \frac{0.388}{11.79} = 0.0329$

$\frac{\sigma u}{\bar{X}} = \frac{0.091}{3.55} = 0.0256$